SHRUBS AND TREE FODDERS FOR FARM ANIMALS

PROCEEDINGS OF A WORKSHOP IN DENPASAR, INDONESIA, 24 – 29 JULY 1989

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IDRC-276e

Shrubs and tree fodders for farm animals

Proceedings of a workshop in Denpasar, Indonesia, 24–29 July 1989

Editor: C. Devendra

IDRC
CANADA

91-01858/

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PO Box 8500, Ottawa, Ont., Canada K1G 3H9

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IDRC-276e

Shrubs and tree fodders for farm animals: proceedings of a workshop in Denpasar, Indonesia, 24–29 July 1989. Ottawa, Ont., IDRC, 1990. xii + 349 pp.:ill.

/Trees/, /fodder/, /feed/, /animal nutrition/, /developing countries/ — /animal husbandry/, /agroforestry/, /ruminants/, /research and development/, /forage/, /case studies/, /conference papers/.

UDC: 636.085 ISBN: 0-88936-556-3

Technical editor: W.M. Carman

A microfiche edition is available.

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Abstract

This publication presents the results of an international meeting held in Denpasar, Bali, Indonesia, 24–29 July 1989, that focused on the use of shrubs and tree fodders by farm animals. Through 26 papers, the workshop addressed feed-resource availability, use by ruminants and nonruminants, processing methodology, economics, and development issues. These aspects and the current knowledge on shrubs and tree fodders were further highlighted by country case studies detailing prevailing situations and policy matters. A special session was held to discuss the successful development and results achieved in the three-strata forage system in Indonesia. The workshop concluded with important working group discussions on the priorities for further research and development, and on the potential for the wider use of shrubs and tree fodders in the developing world.

Résumé

Cette publication présente les résultats d'une rencontre internationale tenue à Denpasar, Bali, Indonésie, du 24 au 29 juillet 1989 et qui a porté sur l'utilisation des arbustes et fourrages végétaux par les animaux d'élevage. Les 26 communications qui y ont été présentées traitaient de la disponibilité des ressources alimentaires pour les animaux, de leur utilisation par les ruminants et les non-ruminants, des méthodes de transformation, des aspects économiques et des questions du développement. Ces sujets et les connaissances actuelles sur les arbustes et les fourrages végétaux ont ensuite été étudiés plus à fond dans le cadre d'études de cas de divers pays exposant les circonstances particulières de chacun et les questions liées aux politiques. Une séance spéciale a porté sur la mise en place et les résultats des systèmes de production de fourrages végétaux en trois strates en Indonésie. L'atelier s'est terminé par d'importantes discussions des groupes de travail sur les priorités de recherche et de développement pour l'avenir et sur les possibilités d'utilisation élargie des arbustes et des fourrages végétaux dans les pays en développement.

Resumen

Esta publicación presenta los resultados de una reunión internacional celebrada en Denpasar, Bali, Indonesia, del 24 al 29 de julio de 1989, y la cual centró su atención en la utilización de forrajes elaborados a partir de arbustos y árboles para alimentar a animales de granjas. En 26 trabajos presentados al seminario, los participantes abordaron temas tales como la disponibilidad de recursos alimentarios y la utilización de los mismos por rumiantes y no rumiantes, metodologías de procesamiento y cuestiones de economía y desarrollo. Estos aspectos y el conocimiento que se tiene actualmente sobre los forrajes de arbustos y árboles se vieron subrayados aún más por estudios de casos por países en los que se detallaron situaciones existentes y cuestiones de políticas. Se celebró una sesión especial para discutir el desarrollo y resultados exitosos alcanzados en Indonesia con el sistema de forraje de tres niveles. El taller concluyó con importantes discusiones de los grupos de trabajo sobre las prioridades existentes en el campo de la investigación y el desarrollo y sobre el potencial que encierra la amplia utilización de arbustos y árboles en el mundo en desarrollo.

Contents

Foreword vii

Acknowledgments ix

Introduction xi

Session I: The Resources

The diversity and potential value of shrubs and tree fodders
G.J. Blair 2

Shrubs and tree fodders in farming systems in Asia
A. Topark-Ngarm 12

Major characteristics, agronomic features, and nutritional value of shrubs and tree fodders
D.A. Ivory 22

Discussion 39

Session II: Use by Farm Animals

The use of shrubs and tree fodders by ruminants
C. Devendra 42

The use of shrubs and tree fodders by nonruminants
P.D. Limcangco-Lopez 61

Toxic factors and problems: methods of alleviating them in animals
J.B. Lowry 76

Discussion 89

Session III: The Three-Strata Forage System

The concept and development of the three-strata forage system
I.M. Nitis, K. Lana, W. Sukanten, M. Suarna, and S. Putra 92

Research protocols appropriate to the development of methodology for the three-strata forage system
K. Lana, I.M. Nitis, M. Suarna, S. Putra, and W. Sukanten 103

Socioeconomic aspects of the three-strata forage system in Bali
I.W. Arga 118

Communication aspects and research extension linkages of the three-strata forage system in Bali
N.K. Nuraini 130

Discussion 136

Session IV: Country Case Studies

Availability and use of fodder shrubs and trees in tropical Africa
A.N. Atta-Krah 140

Potential of legume tree fodders as animal feed in Central America
D. Pezo, M. Kass, J. Benavides, F. Romero, and C. Chaves 163

Availability and use of shrubs and tree fodders in Pakistan
M. Akram, S.H. Hanjra, M.A. Qazi, and J.A. Bhatti 176

Agrosilvipasture systems in India
P. Singh 183

Availability and use of shrubs and tree fodders in India
G.V. Raghavan 196

Availability and use of shrubs and tree fodders in Nepal
N.P. Joshi and S.B. Singh 211

Availability and use of shrubs and tree fodders in Bangladesh
M. Saadullah 221

Availability and use of shrubs and tree fodders in Sri Lanka
A.S.B. Rajaguru 237

Availability and use of shrubs and tree fodders in Thailand
M. Wanapat 244

Availability and use of shrubs and tree fodders in Malaysia
Wong C.C. 255

Availability and use of shrubs and tree fodders in Indonesia
M. Rangkuti, M.E. Siregar, and A. Roesyat 266

Availability and use of shrubs and tree fodders in the Philippines
L.T. Trung 279

Availability and use of shrubs and tree fodders in China
Xu Zaichun 295

Discussion 303

Session V: Processing, Methodology, and Economics

Opportunities for processing and using shrubs and tree fodders
M.R. Reddy 308

Development and evaluation of agroforestry systems for fodder production
A.N. Abd. Ghani and K. Awang 319

Economic aspects of using shrubs and tree fodders to feed farm animals
P. Amir 331

Discussion 340

Conclusions and Recommendations 341

Participants 347

Foreword

Ruminant species, especially buffaloes, cattle, goats, and sheep, are a very important resource throughout the world. They contribute meat, milk, fibre, and draught power, functions that are significant to the productivity, stability, and sustainability of many Third World farming systems. In addition, they serve a variety of other functions that are important within the social context of rural communities. Recognizing the key role of ruminants, IDRC (International Development Research Centre) supports ruminant research in all regions of the tropics and subtropics.

In this support, IDRC places a high priority on multidisciplinary research that recognizes the interdependence of crops and livestock and accounts for the complex farming and social systems in which ruminants are produced and used. Inadequate animal feed is widely regarded as the major constraint to animal production in many parts of the world, and a large proportion of the research supported by IDRC addresses this issue. Although a major part of this research focuses on pastures and the use of crop residues, shrub and tree fodders also receive attention in a range of agroecosystems.

The actual and potential contribution of shrubs and trees is generally well recognized. In northern, arid regions of Africa, for example, it is estimated that browse constitutes 60–70% of rangeland production and accounts for about 40% of the total available feed. Likewise, in the humid regions of Latin America, the Caribbean, Africa, and Southeast Asia, tree fodders, especially leguminous species, are widely used as sources of supplementary, dietary nitrogen for ruminants. Their role is considered especially important in Asia, where small landholdings and large ruminant densities result in an especially severe problem of feed availability from more conventional sources. However, the fact remains that inadequate research attention has been paid to trees and shrubs; in only a few productions systems do they contribute to their maximum potential.

Considering this situation, the Agriculture, Food and Nutrition Sciences Division of IDRC was pleased to be able to assist in organizing and supporting this international workshop. It complements well other activities supported by the Division, such as research on multipurpose trees in agroforestry systems, germ plasm collection, genetic improvement and management of shrubs and trees, and the control of psyllid infestation of *Leucaena leucocephala*. The workshop is timely in the context of global concerns for environmental issues, such as the deterioration of rangeland, soil erosion, and the conservation of forests.

The presentations made at the workshop, which are published here, provide a valuable contribution to our understanding of the management and use of shrubs and trees for fodder and to the current status of research on the subject. The papers have a bias toward Southeast Asia, but there is also coverage of the situation elsewhere and it is expected that these proceedings will provide a valuable reference source for researchers in many parts of the world. It is hoped that the research presented here will stimulate new ideas and lines of research and contribute to the development of innovative feeding systems that will enhance productivity from farm animals on a sustainable basis.

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Acknowledgments

The International Development Research Centre (IDRC) thanks Dr I.G.N.P. Adnyana, the Rector, Dr I.M. Nitis, and their colleagues at Udayana University, Bali, Indonesia, for hosting this workshop and for their valuable support. Special thanks are extended to the several scientists and institutions who participated in this international workshop and contributed to the realization of this publication, and to the Governor of Bali, who graciously opened the week of sessions. The Australian Centre for International Agricultural Research (ACIAR) provided support for one of the participants. Editorial support at the workshop was provided by Dr Amri Jahi. Summaries of individual sessions and group discussions were presented by the following participants: Dr G.B. Blair, Dr J.B. Lowry, Dr D.A. Ivory, Dr G.V. Raghavan, Dr A.S.B Rajaguru, Dr D. Pezo, Mr Wong Choi Chee, and Dr P. Amir.

Introduction

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In pastoral situations and systems combining arable cropping involving herbage, a reference to forages and fodders has commonly focused on the importance of grasses and legumes. This is because grasses and legumes are the main components of diets in traditional feeding systems for ruminants. Consequently, all previous meetings on grasslands and forages have mainly concentrated on varieties available, agronomic aspects, evaluation, and use.

Throughout the tropical developing world, however, in addition to grasses and legumes, shrubs and tree fodders are widely available and traditionally used by farmers. An important feature of shrubs and trees is that they are underused in feeding systems, especially with ruminants. These feeds are valuable supplements, provide considerable variety to grass diets, and have considerable potential in supporting economic animal production. The importance of shrubs and tree fodders becomes even more critical in the context of increasing animal populations and available grazing lands. The available pastureland and corresponding ruminant populations show a marked imbalance in Asia and the Far East compared with Africa and Latin America.

In semi-arid and arid regions, browse, shrubs, and tree fodders become increasingly important as feeds because of the harsh environment and the limited, fluctuating feed supplies. Also, in these same environments, there are large areas of marginal land that cannot support good pasture growth; consequently, browse, the tender shoots of twigs, and leaves of shrubs and trees are often the main sources of feed. Under these circumstances, the value of shrubs and tree fodders are considerable in meeting nutrient needs and maintaining the productivity of ruminant populations. The important conclusion remains, however, that there is an extreme paucity of information on the practical demonstration of the value of shrubs and tree fodders for farm animals.

This scenario justified organizing and supporting this international workshop. Particular emphasis was placed on various aspects and problems of utilization, by both ruminants and nonruminants. This was achieved by discussing many different aspects of shrubs and tree fodders, including prevailing practices in different regions of the developing world. The meeting was attended by 48 participants from 15 countries.

The workshop was structured into six main sessions. The first session addressed the diversity of shrubs and tree fodder resources and their characteristics. The second session examined utilization by both ruminants and nonruminants. The third session was devoted to discussing all aspects of the successful IDRC-supported project on the three-strata forage system in Bali, Indonesia. This system provides green feeds from grasses, shrubs, and trees to Bali cattle year-round in an improved feeding system that has already benefited the island's subsistence farmers, economy, and ecology. The fourth session consisted of 13 case studies that highlighted prevailing patterns of utilization, problems, and policy issues in specific countries. The fifth session discussed processing, methodology, and economics. Given this background, the sixth and final session involved three working group discussions that addressed areas of research and development priorities, research protocols, and future direction. The final objective was to define practical and realistic improvements to feeding and management systems that could be adapted in response to farmer's needs in developing countries.

The workshop provided a valuable opportunity to discuss in detail a subject that has not been adequately addressed before. More particularly, it was timely and beneficial in assessing the state of the art and increasing awareness of these feeds and their potential benefits to national research programs. The workshop also enabled valuable interaction between participants. The results of these efforts, reflected in this publication, will hopefully contribute to a wider appreciation of the potential of shrubs and tree fodders for farm animals throughout the developing world.

Session I

The Resources

The diversity and potential value of shrubs and tree fodders

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Abstract *— There is a wide range of leguminous and nonleguminous tree and shrub fodders that are currently used as animal feeds throughout the world. A compendium of these species is presented. Few quantitative evaluations have been made of the contribution that these materials make to animal production. There are problems associated with such evaluations: e.g., the long growth period to maturity and the difficulty of deciding on experimental conditions such as planting density, cutting height, and cutting frequency. Assessing the feeding value of such fodders is difficult when the proportion in the diet can vary markedly. In all evaluations, there should be a clear definition of the purpose for which the fodder is to be used. The requirements for a sole feed may be quite different from those of a supplement to low-quality roughages. The importance of forage is reflected in the estimated increases in animal production in Southeast Asia and the South Pacific, which will result in forage demand doubling by the year 2000.*

Résumé *— Il y a actuellement dans le monde beaucoup d'arbres et d'arbustes, légumineux ou non, qui servent à l'alimentation du bétail. L'auteur en présente un condensé. On ne sait pas vraiment ce qu'ils contribuent à la production animale parce que trop peu d'évaluations quantitatives en ont été faites. D'ailleurs ce genre d'évaluation pose certains problèmes, notamment la longue période de croissance jusqu'à la maturité de ces végétaux et la difficulté du choix des conditions de l'expérience comme la densité de plantation et la hauteur et la fréquence du rabattage. Évaluer la valeur alimentaire de ces fourrages n'est pas facile quand la proportion qu'ils constituent de la ration alimentaire peut varier énormément. Dans toute évaluation, il faudrait préciser clairement la fin à laquelle le fourrage est destiné. Les exigences, lorsqu'ils constituent la seule ration, différeront de celles pour ces mêmes fourrages employés comme compléments à un fourrage grossier de faible qualité. L'augmentation prévue de la production animale en Asie du Sud-Est et dans le Sud du Pacifique, qui fera doubler la demande de fourrage d'ici l'an 2000, donne une idée de l'importance du fourrage.*

Resumen *— Hay una gama muy variada de arbustos y árboles forrajeros, tanto leguminosos como no leguminosos, utilizados en la actualidad como alimento de animales en todo el mundo. Este estudio presenta un compendio de estas especies. Se han realizado algunas evaluaciones cuantitativas con respecto al aporte de estas plantas forrajeras a la producción de animales. Dichas evaluaciones revelan algunos problemas, por ejemplo, el largo período de vegetación hasta su madurez y las dificultades para tomar decisiones sobre condiciones experimentales, tales como: densidad de plantación, altura de*

corte y frecuencia de corte. Resulta difícil estimar el valor forrajero de dichos piensos cuando la proporción en la ración alimenticia puede variar considerablemente. En toda evaluación, debe haber una definición clara del propósito para el que se utilizará el forraje. Las necesidades pueden ser realmente diferentes según se trate de una única alimentación o de una adición a forrajes groseros de baja calidad. La importancia del forraje está reflejada en las estimaciones de aumento de la producción animal en el sudeste de Asia y el Pacífico sur, que dará por resultado la duplicación de la demanda forrajera para el año 2000.

Projected increases in human population throughout the developing world and the limited availability of land for increased food and forage production suggest that agricultural production will need to be intensified considerably if current human and animal nutritional standards are to be maintained. In many of the ruminant-production systems in the developing world, native or naturalized grass pastures make up the bulk of feed. The low quality and seasonal nature of the forage supply, together with the low intake by animals and the poor digestibility of the forage, are major factors contributing to the low productivity of ruminant animals (Remenyi and McWilliam 1986).

Remenyi and McWilliam (1986) suggest that there will be a doubling in the forage resources required by animals in Southeast Asia and the South Pacific by the year 2000. This is despite a projected drop in meat self-sufficiency from 95% in 1980 to 62% in 2000. The demand for additional forage resources will come from an estimated quadrupling in meat production in the region as well as a requirement for draft power, which is expected to increase by approximately 0.8%/year. Remenyi and McWilliam (1986) also point out that the need is not for forages alone, but for forages within the farming systems adapted to the economic realities of farmers.

Mahadevan and Devendra (1986) suggest that the principle aim of any forage-improvement program should be to maximize the use of basic feed resources, which, in most situations, will be crop residues or low-quality roughages. One suggested method is the addition of leguminous forages that will act as a nitrogen supplement to the low-quality roughage materials.

In considering supplementary feeding of materials, such as those from tree legumes, Preston and Leng (1986) suggest that it is important to identify the order of likely constraints to animal production, and that any one of the following factors may be the first limitation to production:

- insufficient fermentable N in the diet to support efficient rumen function,
- low rate of flow of digest out of the rumen, creating distention and limiting feed intake,
- an imbalance in the protein/energy ratio in absorbed products, depending on the physiological state of the animal and parasite infection,
- lack of overall availability of protein and energy because of low feed intake, and
- mineral deficiencies affecting rumen organisms and the animal.

Preston and Leng (1986) point out that many of these factors are interrelated. They also indicate that, in low-input systems, farmers are unlikely to buy supplemental feed to increase animal production.

It is unreasonable to assume that the addition of shrub or tree leaf material to the diet of ruminants will necessarily lead to increased productivity. Chamberlain et al. (1987) reported that, although there was an increase over time in the population of shrubby stylo (*Stylosanthes scabra*) in the brigalow pastures of southeastern Queensland, there was no effect on the live weight gain of cattle. Obviously, the shrub legume could not alleviate the limiting factor to animal production in this situation. In the context of increasing demand for forages and a large supply of low-quality basal diet material, however, high-protein tree legumes are likely to play a significant role in maintaining and perhaps increasing animal productivity in the developing world.

Diversity of fodder trees and shrubs

Many tree and shrub species have been documented as useful animals fodders. These range from short-stature shrubs such as *Desmodium discolor* to trees such as *Pterocarpus marsupium*, which can grow to a height of 30 m. Listings of trees and shrubs of potential value as animal fodders have been published by Skerman (1977), ILCA (1985), Brewbaker (1986), and Turnbull et al. (1986). A compendium of these lists is presented in Appendix 1, which includes some 74 genera. Many collections contain numerous accessions within a species. For example, ILCA (1985) lists 26 accessions of *Aeschynomene americana* and 96 accessions of *Cajanus cajan* in their collection.

Brewbaker (1986) points out that most trees lopped for fodder do not fix nitrogen and lists the highly productive, non-nitrogen-fixing trees as follows:

- nonnodulating legumes: *Bauhinia*, *Cassia*, *Ceratonia*, *Cerdicium*, *Gleditschia*, and *Parkinsonia*; and
- nonleguminous trees: *Artemisia*, *Artocarpus*, *Atriplex*, *Azidirachta*, *Ficus*, *Haloxylon*, *Morus*, and *Quercus*.

Soedomo et al. (1986) list a range of trees categorized by the National Academy of Science (NAS 1980) as having a primary role in fuel production and a secondary forage role (Table 1). Some 43 species of nonleguminous fodder trees have been recorded by Nitis et al. (1985) as being useful in Bali, Indonesia. A wide range of

Table 1. Tree and shrub genera identified as having a prime role in fuel production and a secondary forage role.

Region	Family	Genus	Plant parts eaten by livestock
Humid tropics	Sterculiaceae	*Gauzuma*	Young foliage, fruits
	Ulmaceae	*Trema*	Leaves, branches
Tropical highlands	Ulmaceae	*Trema*	Leaves, branches
Arid and semi-arid tropics	Combretaceae	*Anogeissus*	Foliage
	Euphorpiaceae	*Emblica*	Foliage, fruits
	Chenopodiaceae	*Haloxylon*	Foliage
	Rhamnaceae	*Zizyphus*	Foliage, fruits

Source: NAS (1980).

tree and shrub species have been identified as being useful contributors to animal production in various parts of the world. However, few comparative trials have been undertaken to evaluate the impact of these forages on animal production.

Potential value of fodder trees and shrubs

Three of the major difficulties encountered in evaluating the agronomic performance and feeding value of tree and shrub forages are

- the long growth cycle of some species,
- deciding on the experimental management system for growing (e.g., density) and harvesting (i.e., frequency, severity, plant part) that can be used for each species, and
- establishing an experimental procedure for feeding trials to evaluate the fodder.

With respect to this final problem, three questions are important:

- What proportion of the diet should be tree or shrub leaf?
- Should single or mixed species of fodders be used?
- What animal species should be used in the evaluation study?

Blair et al. (1988) undertook an evaluation of 17 tree species in an acid Ultisol soil in southern Sumatra, Indonesia, using a uniform cutting height of 1 m and a cutting interval of approximately 3–4 months after an initial growth period of 2 years. Maximum leaf and wood production over the 4-year period was from *Acacia mangium* and *Cassia siamea* (Table 2). These two species also had the highest wood production. These studies also highlighted seasonal differences in leaf production between the species; this could have important implications for animal production. In another evaluation of tree and shrub species carried out in Indonesia, Ella (1987) used a different cutting height for different species based on the growth habit of each species.

In addition to there being little comparative data on species dry matter yields, there is also little information available on fodder "quality" aspects of tree and shrub forages. Ashew and Mitchell (1978) classified 19 nonleguminous species that are used as fodder in the Northern Territory of Australia on a scale ranging from excellent to poor in relation to protein, phosphorus (P), calcium (Ca), magnesium (Mg), and digestibility.

The nitrogen content of the eight tree legumes listed in Table 3 is at or above 1.8%, the level required for finishing cattle weighing 300–500 kg, but below the P concentration of 0.22% recommended by Minson et al. (1976). The concentrations of K, Ca, and Mg in all species were above the levels of 0.31–0.44, 0.22–0.35, and 0.12%, respectively, but only *Acacia mangium* and *Acacia auriculiformis* had Na levels above 0.05%, levels which Minson et al. (1976) suggested as critical for animal production. The S concentration varied markedly between species.

Wilson et al. (1966) have shown a negative relationship in sheep between fodder intake and crude fibre, neutral-detergent fibre (NDF), and acid-detergent fibre

Table 2. Species planted at Nakau, southern Sumatra, and total leaf yield (g dry matter/tree) and wood yield (g fresh weight/tree) harvested from January 1982 to April 1986.

Species	NFTA[a] Code No.	Leaf yield	Wood yield
Acacia mangium	N6	3802	14928
Cassia siamea	Local	3723	12654
Acacia auriculiformis	N72	2251	8654
Albizia falcataria	N10	1424	8048
Calliandra calothyrsus	N63	2172	7178
Enterolobium cyclocarpum	N20	1374	4954
Acacia sp.[b]	Local	1782	2783
Leucaena leucocephala	K8	1490	7526
Cassia fistula	Local	1406	2752
Eucalyptus saligna	USFS	401	2668
Leucaena diversifolia	K156	491	3424
Mimosa scabrella	N39	120	385
Gliricidia sepium	N54	1280	3035
Albizia procera	N53	1112	793
Sesbania grandiflora	N67	8	275
Dalbergia sissoo	K18	53	91
Samanea saman	N25	11	7
SE (df = 4,12)		237	1247

[a] NFTA, Nitrogen-Fixing Tree Association.
[b] Originally wrongly identified as *Cassia orrania*, possibly *Acacia angustissima*.

Table 3. Analysis of feed constituents (%) of composite leaf samples taken in January 1984 from trees planted in January 1982 that had been cut to 1 m 3 months before sampling.

Species	NDF[a]	ADF[b]	Lignin	N	P	S	K	Ca	Mg	Na
Acacia mangium	61.9	61.0	42.2	1.92	0.08	0.24	0.91	1.33	0.30	0.19
Cassia siamea	45.6	43.5	25.3	1.99	0.15	0.18	1.12	1.63	0.26	0.02
Acacia auriculiformis	64.3	58.4	39.5	1.91	0.09	0.24	1.32	1.92	0.27	0.11
Albizia falcataria	61.8	63.0	47.3	3.09	0.15	0.26	1.32	1.25	0.57	0.01
Calliandra calothyrsus	63.4	70.1	51.9	2.19	0.11	0.28	0.69	1.03	0.37	0.01
Enterolobium cyclocarpum	36.1	29.6	14.1	2.69	0.16	0.28	1.31	0.87	0.23	0.01
Gliricidia sepium	55.1	46.6	31.3	2.49	0.11	0.21	0.96	2.18	0.86	0.02
Albizia procera	64.0	65.4	41.6	1.76	0.08	0.17	1.07	0.66	0.28	0.01

Source: Blair et al. (1988).
[a] NDF, neutral-detergent fibre.
[b] ADF, acid-detergent fibre.

(ADF) contents. Bamualin et al. (1980) also found that nylon-bag dry matter digestibility of browse legumes was negatively correlated with NDF, ADF, and lignin, and positively correlated with N and ash contents. It would be expected, therefore, that the voluntary intake of species listed in Table 3 such as *A. mangium*, *A. auriculiformis*, *Albizia falcataria*, *Calliandra calothyrsus*, and *Albizia procera* would be low, with *C. calothyrsus* being the lowest. The voluntary intake of *Enterolobium cyclocarpum* and *Cassia siamea* would be expected to be higher. However, in intensive tropical production systems, where feed is cut and carried to livestock and a mixture of forages is generally fed as chopped material, the criterion of voluntary intake may not be as important as it is for free-grazing animals.

Leng (1986) points out that requirements differ according to whether feeds are used alone or as a diet supplement. Leng (1986) indicates that for a sole feed source, a good-quality forage should possess the following attributes:

- high feed digestibility (i.e., 65%),
- soluble protein in the diet providing about 30 g N/kg digestible dry matter (DDM),
- bypass protein providing about the same amount of protein as arises from microbes (i.e., 200 g protein/kg DDM intake),
- a level of fat in the diet approaching that of temperate pastures (i.e., 4–8% dry matter), and
- glucogenic energy comprising a high proportion of the volatile fatty acid energy absorbed from the rumen (i.e., 25%).

Because supplements are generally fed at below 15% of total feed intake, the concentration of the nutrients required in a supplement, such as tree or shrub fodder, when fed with poor-quality roughage such as native grass or crop residues, is five times that indicated for a complete feed.

Some tree and shrub fodders are noted for their antinutritive factors. Duke (1981) lists 97 "toxins" found in legume species. Skerman (1977) points out that hungry animals given free access to unaccustomed species will often consume too much and this may prove fatal. There are also differences between animals in their tolerance to toxicities. Jones and Lowry (1984) found that Australian goats lacked rumen microorganisms capable of degrading toxic mimosine; however, when the animals were inoculated with the appropriate organisms, the "toxicity" of *Leucaena* was no longer a problem. This approach of inoculating animals with rumen microorganisms could be used to alleviate toxic effects from other potentially useful shrub genera such as *Indigofera* and *Crotalaria*. With cut-and-carry systems, the animal raiser has a great deal of control over the quantity of potentially toxic materials that are fed to the animals, therefore, the antinutritive problem is less significant.

Conclusions

A wide range of tree and shrub fodders are used in various parts of the world. For most of these fodders there are no quantitative data on their contribution to animal production. There are also few data on the relative agronomic performance of tree and shrub fodders. Such data are urgently needed if the real potential of these fodders is to be realized. In such evaluations, the management conditions selected should allow each accession to express its full potential.

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Appendix 1. Tree and shrub fodders documented as being useful animal fodders.

Acacia accola
A. acuminata
A. adsurgens
A. albida
A. aneura
A. angustissima
A. arabica
A. argyrodendron
A. aulacocarpa
A. baileyana
A. bidwillii
A. brachystachya
A. brevispica
A. burrowii
A. cambagei
A. cana
A. catechu
A. catenulata
A. chisholmi
A. coriacea
A. cunninghamii
A. cyclops
A. cyperophylla
A. dealbata
A. deanei
A. decora
A. decurrens
A. doratoxylon
A. estrophiolata
A. excelsa
A. farnesiana
A. floribunda
A. georginae
A. gerrardii
A. giraffae
A. hakeoides
A. harpophylla
A. holosericea
A. homalophylla
A. horrida
A. karroo
A. kampeana
A. koa
A. leptoclada
A. ligulata
A. linifolia
A. linophylla
A. litakunensis
A. macrothyrsa
A. melanoxylon
A. mellifera
A. microbotyra
A. myrtifolia
A. nigrescens
A. nilotica
A. nubica
A. oswaldii
A. pendula
A. penninervis
A. peuce
A. plectocarpa
A. podalyraefolia
A. polycantha
A. pruinocrapa
A. pycnantha
A. retinodes
A. salicina
A. saligna
A. sclerosperma
A. senegal
A. seyal
A. shirleyi
A. sieberiana
A. sophorae
A. sparsiflora
A. stenophylla
A. suavolens
A. subulata
A. sutherlandii
A. tephrina
A. tenuissima
A. tetragonophyll
A. tortilis
A. trineura
A. tumida
A. verticillata
A. victoriae
Aeschynomene abyssinica
A. americana
A. brasiliana
A. elaphroxylon
A. falcata
A. histrix
A. schimperi
A. sensitive
A. villosa
Albizia adianthifolia
A. africana
A. amara
A. basaltica
A. falcata
A. harveyi
A. julibrissin
A. lebbek
A. lophantha
A. malacophylla
A. toona
A. zygia
Allocasuarina decaisneana
A. littoralis
Alphitonia excelsa
Antiaris africana
Atalaya hemiglauca
A. atacamensis
A. bunburyana
A. canescens
A. cinerea
A. confertifolia
A. glauca
A. halimus
A. lentiformis
A. leucoclada
A. linearis
A. nummularia
A. polycarpa
A. rnagodioides
A. semibaccata
A. undulata
A. vesicaria
Atylosia scarabaeoides
Azadirachta indica
Banksia integrifolia
Baphia nitida
Bauhinia purpurea
B. retusa
B. refescens
B. variegata
Brachychiton populneum
Brachistegia spiciformis
Buckinghamia celsissmia
Cajanus cajan
Calliandra calothyrsus
C. surinamensis
Callitris endicheri
Cassia artemisioides
C. brewsteri
C. chatelainiana
C. eromophila
C. nemophila
C. oligophulla

(continued)

Appendix 1. Concluded.

C. siamea
C. sturtii
Casuarina cristata
C. cunninghamiana
C. decaisneana
C. obesa
C. stricta
Celtis kraussiana
Ceratonia siliqua
Chamaecytisus palmensis
Codariocalyx gyroides
Colophospermum mopane
Combretum imberbe
Cordia africana
Crotalaria anagyroides
Cyamopsis tetragonoloba
Dalbergia sissoo
Daniella oliveri
Desmanthus barbatum
D. virgatus
Desmodium capitatum
D. cinereum
D. discolor
D. distortum
D. gyroides
D. lasiocarpum
D. tortuosum
Dicrostachys cinerea
Dodonaea viscosa
Dovyalis sp.
Enrharta calcycina
Entada abyssinica
E. africana
Eriosema psoraloides
Eremophila leucophylla
E. longifolia
E. maculata
Eriocephalus ericoides
E. umbellatus
Erythrina abussinica

E. brucei
E. burana
E. melanacantha
Eucalyptus brevifolia
E. gamophylla
E. gongylocarpa
E. ochrophloia
Exomis microphylla
Felicia filifolia
F. muricata
Ficus thonningii
Flemingia macrophylla
Geijera parviflora
Gleditsia triacanthos
Gliricida sepium
Griffonia simplicifolia
Guazuma ulmifolia
Hermannia trifurcata
Hirpicium integrifolium
Indigofera arrecta
Kigelia africana
Leucaena chennoni
L. collinsii
L. diversifolia
L. leucocephala
L. pulverulenta
Lonchocarpus capassa
Lophira procera
Maireana brevifolia
M. polypterygia
Medicago arborea
Millettia thonningii
Monochlamys albicans
Moringa oleifera
Napoleona vogeli
Newbouldia laevis
Olea africana
Osteospermum pachypteris
O. scariosum
O. sinuatum

Parkia clappertoniana
Parkinsonia aculeata
Peltophorum pterocarpum
Pentzia lanata
Piliostigma thonningii
Pithecolobium dulce
Pittosporum phylliraeoides
Pollichia campestris
Prosopis alba
P. chilensis
P. cineraria
P. glandulosa
P. juliflora
P. pallida
P. spicigera
P. tamarugo
P. velutina
Pterocarpus erinaceus
P. marsupium
P. santalinoides
Ptilotus obovatus
Rhigozum obovatum
Ricinodendron headelotti
Robinia pseudoacacia
Samanea saman
Santalum spicatum
Sesbania aculeata
S. formosa
S. grandiflora
S. rostrata
S. sesban
Simmondsia chinensis
Spondias mombin
Tamarindus indica
Terminalia arostrata
Tetragonia hirsuta
Ventilago viminalis
Vernonia amygdalina
Zizyphus nummularia

Source: Skerman (1977), ILCA (1985), Brewbaker (1986), Turnbull et al. (1986).

Shrubs and tree fodders in farming systems in Asia

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Abstract *— Farming systems in Asia normally include small-scale crops and livestock. The performance and productivity of the farm animals are generally poor because of the limited farm area and animal feeds, especially during the dry season. Shrubs and tree fodders are one solution to the feed problem. In general, the shrubs or trees can be incorporated economically into the farm as a living fence around the household, vegetation on the farm's uncropped areas, hedgerows in alley cropping, or as a component species of intercropping. However, shrubs and tree fodders are relatively underused. The establishment techniques and benefits of useful shrubs and trees are discussed. More information on species adaptation, nutritive value, and crop management are needed to use shrub and tree fodders more efficiently in farming systems.*

Résumé *— Les cultures et l'élevage à petite échelle sont habituellement présents dans les systèmes d'exploitation agricole de l'Asie. Les exploitants ne tirent généralement pas un bon rendement de leurs animaux en raison de la petitesse de leur exploitation et la quantité limité de fourrage dont ils disposent, surtout durant la saison sèche. Les arbustes et arbres fourragers offrent une solution au problème. La plupart du temps, arbustes et arbres peuvent être ajoutés économiquement à l'exploitation agricole sous forme d'une haie vive autour de la maison, de végétation sur les terres non cultivées, de rangée-haie dans la culture en couloirs ou d'une culture dans la culture intercalaire. Malgré tout, arbustes et arbres fourragers sont sous-utilisés. L'auteur discute des techniques d'établissement d'arbustes et d'arbres utiles et des avantages à en tirer. Il reste encore à obtenir plus d'information sur l'adaptation des espèces d'arbustes et d'arbres fourragers, leur valeur nutritive et leur gestion avant de pouvoir mieux les utiliser dans les systèmes d'exploitation agricole.*

Resumen *— Los sistemas de explotación agrícola de Asia normalmente incluyen cultivos en pequea escala y ganadería. El rendimiento y la productividad de los animales de granja generalmente son escasos, especialmente durante la sequía, por la poca alimentación que reciben y la limitada superficie de la granja. Los arbustos y árboles forrajeros representan una de las soluciones del problema alimenticio. Por lo general, los arbustos y árboles pueden incorporarse económicamente a la granja en forma de cerco viviente, alrededor de la casa, como vegetación en las superficies sin cultivar, como seto vivo en hileras en callejones, o como especies componentes de cultivos intermedios. Sin embargo, los forrajes de arbustos y árboles no se utilizan suficientemente. Este estudio trata de los beneficios y las técnicas de implantación de árboles y arbustos útiles. Para que los árboles y arbustos forrajeros sean utilizados más eficientemente en los sistemas de explotacion agrícola, es necesario obtener mayor información sobre la adaptación de las especies, el valor nutritivo y la explotación del cultivo.*

Introduction

In Asia, farming systems normally include crop and livestock components. Farmers grow crops and raise a few nonruminant animals, such as pigs and poultry, for cash and family consumption. They also raise cattle, buffalo, sheep, and goats as capital investment and for additional income (Carangal and Club 1986). Cattle and buffalo are commonly used to provide farm power, transportation, manure, and fuel. However, although these animals are of value to the farm, their performance and productivity are generally poor because of the limited farm area, low inputs, and low quality and quantity of animal feed (Topark-Ngarm et al. 1989). The animals consume natural herbage, rice straw, crop residues, and crop by-products.

The situation becomes serious during the dry season, under rain-fed conditions, when almost all crops cannot be grown, and natural pasture, grasses, and weeds become unproductive. Farmers either feed their animals with the low-quality hay of the stored crop residues or they travel long distances to gather green grasses or fodders. In such circumstance, shrubs and fodder trees are able to withstand the drought, stay green, and provide a solution to the problem.

There are many shrub and tree species in the tropics and subtropics that can supply fodders; however, they must be used more efficiently. This paper discusses possibilities of including shrub and tree fodders in farming systems in Asia.

Incorporation of fodder shrubs and trees

In conventional farming systems, shrubs and trees can be incorporated into the farm to provide fodder and other benefits in four ways:

- living fence around the household,
- vegetation in uncropped areas,
- hedgerows in alley cropping, and
- as a component species in intercropping.

Living fence around the household

Recently, farmers have tended to create a living fence around their household. Shrubs and fodder tree species, such as *Leucaena leucocephala*, *Pithecellobium dulce*, *Gliricidia sepium*, *Sesbania glandiflora*, and *Artocarpus heterophyllus*, are being increasingly used as living fences to provide not only human food and fuelwood but also animal feed.

In northeastern Thailand, leucaena was widely promoted for the household living fence in rural villages during the early 1980s. The fence was normally established by direct seeding or transplanted seedlings at close spacing. With a little farm manure and crop nursing, these living fences were ready for use 6–8 months after establishment. *Gliricidia sepium* has been used extensively in village households in Indonesia and the Philippines (Nitis et al. 1985; Gonzal and Raros 1988). In this case, the fences are established by sticking the stem or branch cuttings into the ground. During the wet season, the gliricidia cuttings become productive 4–6 months after planting. The fodder from such living fences provides a good daily feed supplement for the livestock.

Vegetation on uncropped areas

Because of constraints on location, environment, or management, most smallholder farms in developing countries always have some waste or fallow land that cannot be used for cropping. These uncropped areas, in the form of farm boundaries, paddy bunds, or forest margins, could be used to grow some shrubs or fodder trees. Because of their deep-rooted nature, most shrubs and trees in the tropics can withstand poor soil or drought stress and provide green foliage throughout the year. They can be an important source of animal feed, particularly during the dry season, when forages from other sources are in short supply. Multipurpose trees can also be grown in uncropped areas to yield twigs for fuelwood, flowers, pods, or fruits for human food, and leaves for animal feed. Some of the predominant shrub and tree species found in Asia (Table 1) have been well studied and used, but others need to be assessed more thoroughly.

Prosopis cineraria is grown extensively in the arid parts of India, where the annual rainfall varies from 200 to 500 mm (Tejwani 1988). It takes 10–20 years, depending on soil type and rainfall, for the plant to become useful. However, every part of the tree can be used. Leaves and tender twigs are used as fodder, branches as fuelwood, green and dry pods as vegetable, ripe pods as fruit, and flowers and bark as medicine.

In Nepal, although the concept of planting woody species on farm and marginal lands is not entirely new, the planting of multipurpose trees is still somewhat limited. Most farmers believe that trees compete with agricultural crops for water, light, nutrients, and space; therefore, they are not motivated to plant trees (Sapkota 1988). However, some local species, such as *Artocarpus lakoocha*, *Bauhinia purpurea*, *Bauhinia variegata*, and various *Bambusa* spp., are preferred by small farmers because of their many uses including fodder. In Thailand, reports on the use of shrub and tree fodders are relatively limited, but it is often observed that the villagers feed tree leaves to their cattle and buffalo when green feeds are not available during the dry season. John Niezen (cited in Manidool 1986) surveyed the current uses of local tree leaves as animal feed in the northeastern Thailand. The preferable nonlegume fodder trees were *Pterocarpus macrocarpus*, *Xanthophyllum glaucum*, *Samanea saman*, *Bambusa* spp., and *Streblus asper*; preferred legumes were *L. leucocephala*, *S. glandiflora*, *G. maculata*, and *Erythrina* spp. In Bali, Indonesia, where cattle raising is a major enterprise, Nitis et al. (1985) listed over 40 species of nonleguminous fodder tree that have been recorded as being used. It is believed that at least 20 leguminous shrub and tree species are being used for the same purpose: *L. leucocephala*, *G. sepium*, and *S. glandiflora* are among the most popular leguminous fodder trees. Sriskandarajah (1989) reported a total leaf dry matter yield of 2.34 kg/plant for *G. sepium* grown at 50-cm spacing and 3-month cutting intervals over 1 year in Papua New Guinea.

Hedgerows in alley cropping

The concept of alley cropping using leguminous shrubs or trees as the hedgerow was developed at the International Institute of Tropical Agriculture (IITA) in the

Table 1. Multipurpose shrubs and trees predominantly grown in some Asian countries.

Country	Species	Use[a]	Source
Bangladesh	*Acacia catechu*	1,2,3	Abedin et al. (1988)
	Acacia milotica	1,2,3,4	
	Artocarpus heterophyllus	1,2,3,4	
	Borassus flabellifer	1,2,3,4	
	Mangifera indica	1,2,3,4	
	Phoenix sylvestris	1,2,3,4	
India	*Acacia albida*	1,2,3	Tejwani (1988)
	Albizia lebbek	1,2,3,4	
	Bambusa arundinaea	1,2,3,4	
	Cassia saimea	1,2,3,4	
	Celtis australis	1,2,3	
	Gliricidia sepium	1,2,3	
	Grewia optiva	1,2,3	
	Leucaena leucocephala	1,2,3,4	
	Mangifera indica	1,2,3,4	
	Moringa oleifera	1,4	
	Morus serrata	1,2,3	
	Prosopis cineraria	1,2,3,4	
	Pterocarpus marsupium	1,2,3,4	
	Sesbania sesban	1,2	
	Zizyphus nummularia	1,2,3,4	
Indonesia	*Acacia farnesiana*	1,2	Nitis et al. (1985)
	Acacia leucophloea	1,2	
	Albizia falcataria	1,2,3	
	Artocarpus heterophyllus	1,2,3,4	
	Calliandra calothrysus	1,2	
	Codariocalyx gyroides	1,2	
	Flemingia congesta	1,2	
	Gliricidia sepium	1,2,3	
	Hibiscus tileaceus	1,2	
	Leucaena leucocephala	1,2,3,4	
	Melochia umbellata	1,2,3	
	Pithecellobium dulce	1,2,4	
	Sesbania sesban	1,2,3	
	Trema orientalis	1,2,3	
Nepal	*Acacia catechu*	1,2,3	Sapkota (1988) and Shakya (1988)
	Albizia chinensis	1,2,3	
	Albizia lebbek	1,2,3,4	
	Alnus nepalensis	1,2,3	
	Artocarpus lakoocha	1,2,3,4	
	Bauhinia purpurea	1,2,3	
	Bauhinia variegata	1,2,3,4	
	Butea monosperma	1,2,3	
	Cassia siamea	1,2,3	
	Celtis australis	1,2,3	
	Dalbergia sissoo	1,2,3	
	Erythrina suberosa	1,2,3	
	Leucaena leucocephala	1,2,3,4	
	Sesbania sesban	1,2	

(continued)

Table 1. Concluded.

Country	Species	Use[a]	Source
Philippines	*Albizia falcataria*	1,2,3	Siapno (1986) and Mangaoang and Rasos (1988)
	Anthocephalus chinensis	1,2,3	
	Anthocephalus heterophyllus	1,2,3,4	
	Bambusa spp.	1,2,3	
	Gliricidia sepium	1,2,3	
	Hibiscus tileaceus	1,2	
	Leucaena leucocephala	1,2,3,4	
	Moringa oleifera	1,4	
	Samanea saman	1,2,3	
	Sesbania sesban	1,2,3	
Thailand	*Albizia falcataria*	1,2,3	Manidool (1986) and Yantasath (1988)
	Albizia lebbek	1,2,3,4	
	Artocarpus heterophyllus	1,2,4	
	Bambusa spp.	1,2,3,4	
	Cassia siamea	1,2,3	
	Erythrina suberosa	1,2,3	
	Gliricidia sepium	1,2,3	
	Leucaena leucocephala	1,2,3,4	
	Pithecellobium dulce	1,2,4	
	Pterocarpus macrocarpus	1,2,3	
	Samanea saman	1,2,3	
	Sesbania glandiflora	1,2,3,4	
	Strebus asper	1,2	
	Xanthophyllum glaucum	1,2,3,4	

[a] 1, fodder; 2, firewood, fuelwood; 3, timber; 4, human food.

late 1970s (Wilson and Kang 1982). In fact, traditional farmers in Africa and Asia have used hedgerows in agroforestry systems for a long time (Metzner 1987). Normally, hedgerows serve as windbreak or heat break and provide green manure fertilizer for annual field crops. There is an increasing trend to select species for use in hedgerows based also on fodder production ability. During the productive period, the cut material from the hedgerow species often provides fodder in excess of the amount needed for green manure; leaves and shoots are then used as fodder for animals.

Leucaena leucocephala and *G. sepium* are the dominant species used as hedgerows in alley cropping because of their desirable growth habits and leaf production. These two species are fast-growing, small trees that can easily reach a height of 2–3 m within 1 year from planting the seeds. Also, the trees can be forced to grow with less branching by planting them at high density within a row. This gives the annual intercrop more room for growth. Both leucaena and gliricidia are tolerant to frequent trimming or lopping, yielding satisfactory amounts of nutritive leaf material.

In a leucaena–maize alley cropping experiment on the Kenyan coast (Macklin et al. 1988), *L. leucocephala* was planted as hedgerows at four within-row spacings (0.5, 1, 2, and 3 m) and three between-row spacings (2, 4, and 8 m), giving 12 different planting arrangements. The trees were grown for 3 years before four successive crops of maize and pulse were planted in 1985 and 1986 (one maize crop and one pulse crop within a year). In both years, before the maize was sown, the leucaena was pruned to a height of 0.5 m. The cutting was repeated twice at about 6 and 12 weeks after planting maize. In such systems, leucaena green leaf yields ranged from 4.5 to 28.3 t/ha in the first cropping year and from 6.6 to 32.2 t/ha in the second year (Table 2). The maize yields under leucaena alley cropping were 2 030–4 000 and 690–2 600 kg/ha in the 1985 and 1986 cropping seasons, respectively. The yields of maize in monocropping in 1985 and 1986 seasons were 2 526 and 475 kg/ha, respectively. This study clearly showed the benefit of having leucaena hedgerows in maize cropping. In Western Samoa, Kidd and Taogaga (1985) got satisfactory results from using fodder trees as hedgerows in taro alley cropping. Among the six tree species used, *G. sepium* and *L. leucocephala* were the best, giving annual herbage dry matter yields of 7.9 and 10.7 t/ha and increasing taro yields about 52 and 30%, respectively, over the control (Table 3).

Perennial *Sesbania* spp. can also be used as hedgerows in alley cropping. Most reports indicate that the crude protein content of both *Sesbania sesban* and *S. glandiflora* foliage is generally greater than 20% and often above 25%. Together with the generally low crude fibre content (5.1–18.4%) and high phosphorus levels (0.24–0.45%), this emphasizes the potential of these species to produce high quality fodders (Topark-Ngarm and Gutteridge 1989). Evans and Rotor (1987) compared *S. sesban* and *S. glandiflora* with *L. leucocephala* and *Calliandra calothyrsus* under irrigation in Hawaii and obtained herbage yields up to 20 t dry matter/ha from *S. sesban* accessions cut 5 or 6 times during the 1st year. In

Table 2. Green leaf yields (t/ha per cropping season) of 3- and 4-year-old leucaena in a leucaena–maize alley cropping with four within-row spacings at Mtwapa, Kenya.

Between-row spacing (m)	Year	0.5 m[a]	1.0 m	2.0 m	3.0 m
2	1985	28.3	17.4	13.9	11.3
	1986	32.2	16.9	14.1	14.0
4	1985	16.3	8.8	4.5	8.2
	1986	20.4	11.5	12.2	7.8
8	1985	12.1	6.2	4.6	4.5
	1986	12.9	9.7	6.7	6.6

Source: Adapted from Macklin et al. (1988).
[a] Within-row spacing.

Table 3. Herbage and taro yields of a taro–legume tree agroforestry trial in Western Samoa, 1983–84.

Species	Tree biomass, dry matter (t/ha per year)	Taro yield, fresh weight (t/ha per cycle)
Calliandra calothyrsus	12.2	3.10
Leucaena leucocephala (cv. K8)	0.7	4.58
Gliricidia sepium	7.9	5.42
Samanea saman	6.9	3.44
Sesbania glandiflora	6.1	3.89
Erythrina spp.	3.0	4.32
Control	—	3.55

Source: Adapted from Kidd and Taogaga (1985).

northeastern Thailand, Akkasaeng et al. (1989) found the in vitro dry matter digestibilities (IVDMDs) of *S. glandiflora*, *S. sesban*, and *S. sesban* var. *nubica* were 66, 75, and 66%, respectively. These values were higher than the IVDMDs of the 15 other tree legumes evaluated.

Component species in intercropping

In intercropping, shrubs or fodder trees are grown in alternate rows or rows adjacent to annual food crops. The trees may be pruned 1 or 2 times for fodder or to reduce shading and competition during the growing period of the food crops. However, the shrubs and fodder trees that can be used in intercropping are limited: only fast-growing species tolerant to low and frequent cutting may be used. Normal-sized shrubs or trees are too competitive, especially with respect to light and rooting systems, for the annual field crops grown in alternate or adjacent rows. Small shrub legumes like *Stylosanthes secabra*, *Stylosanthes viscosa*, *Cajanus cajan*, or *Desmanthus virgatus* can be grown simultaneously with some food crops without significant reduction in crop yield. *Desmanthus virgatus* may be best suited to the intercropping system. It is similar to leucaena but smaller in size. It is also tolerant to low and frequent cuttings, even during the dry season, and is relatively free of disease and insect pests. Its herbage yield and palatability are also good.

At the International Rice Research Institute (IRRI) in Los Baños, Philippines, experiments were conducted to test the performance of *D. virgatus* intercropped between rows of cereals (upland rice, corn, and sorghum) and grain legumes (cowpea, mungbean, and peanut) on rain-fed upland (Fig. 1). During one rainy season, two successive crops of cereal or grain legume were grown together with one continuous crop of *Desmanthus*. The results (Table 4) showed that, in all but one case, food crops yields were unaffected by *Desmanthus* intercropping. In

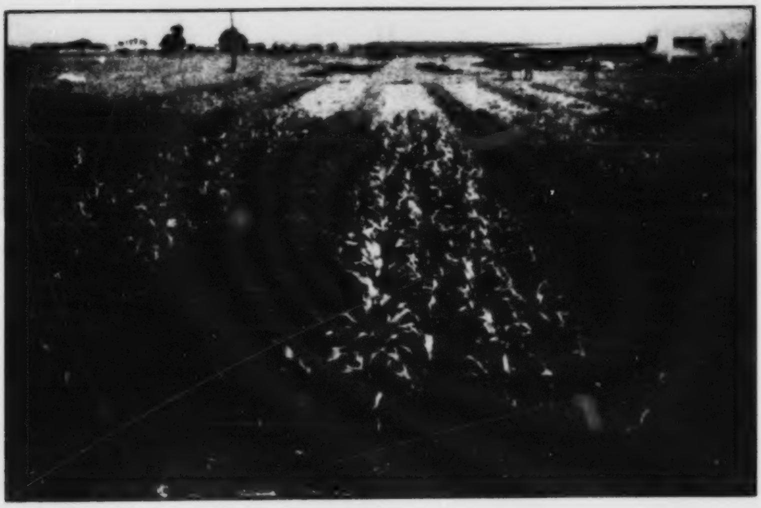

Fig. 1. *Desmanthus*–maize alley cropping system in a rain-fed upland area in the Philippines.

Table 4. Dry matter yield (t/ha) of food crop plus *Desmanthus virgatus* intercroppings on a rain-fed upland at the International Rice Research Institute, Los Baños, Philippines, in 1987.

Crop(s)	First food crop		Second food crop		After food crop	Whole year	
	Grain	Forage	Grain	Forage	Forage	Grain	Forage
Upland rice	0.94	—	0.02	—	—	0.96	—
Upland rice + *D. virgatus*	1.47	0.77	0.05	1.73	6.85	1.52	9.40
Corn	1.54	—	1.14	—	—	2.68	—
Corn + *D. virgatus*	1.68	0.21	0.96	1.22	5.60	2.64	7.03
Sorghum	3.28	—	2.00	—	—	5.28	—
Sorghum + *D. virgatus*	4.35	0.04	2.22	0.80	4.39	6.57	4.69
Cowpea	0.71	—	0.35	—	—	1.06	—
Cowpea + *D. virgatus*	0.36	0.01	0.31	0.99	4.41	0.94	5.41
Mungbean	0.76	—	0.16	—	—	0.92	—
Mungbean + *D. virgatus*	0.57	0.28	0.08	3.25	4.70	0.65	8.23
Peanut	1.48	—	1.09	—	—	2.57	—
Peanut + *D. virgatus*	1.11	0.34	0.31	3.63	5.46	1.42	9.43

addition, *Desmanthus* also provided considerable amounts of forage, ranging from 0.84 to 3.97 t dry matter/ha during the wet season and from 4.69 to 9.43 t dry matter/ha when it was continuously grown and harvested throughout the year.

In Maharashtra, India, *Desmanthus* was compared with *S. sesban*, *S. glandiflora*, and *L. leucocephala* in an intercropping experiment (Evans and Rotar 1987). The trees were planted at spacings of 1.0, 1.5, and 2.0 m between rows and 25 cm within rows. The intercrop cereal crops were millet followed by wheat. The vigorous growth of *S. sesban* tended to suppress crop yields; however, *D. virgatus*, the least competitive fodder tree, generally improved grain yield and produced higher immediate economic returns.

Conclusion

Although shrubs and fodder trees are available and can provide valuable feed supplies, especially during the dry season, to livestock in smallholder farms, they are underused in many countries of Asia. This is probably related to the farmers' unawareness of the potential of tree fodders. Limits to cultivated land and a lack of knowledge about tree management also make small-scale farmers reluctant to grow more trees on their properties. To expand the use of shrub and tree fodders, more information on species adaptation is needed, so that suitable shrub and tree species can be selected for different environments. More information on the proper management of each species is also required. More research should be directed at alley cropping and intercropping involving shrubs and fodder trees, leading to self-sufficient or sustainable farming systems.

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Major characteristics, agronomic features, and nutritional value of shrubs and tree fodders

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Abstract *— Shrubs and trees, particularly leguminous species, are increasingly being used to provide a strategic source of high-quality forage for supplementary feeding to farm animals. This paper reviews research aimed at identifying suitable species for forage and other multipurpose uses. Research has concentrated on evaluating species adaptation to various climatic and edaphic conditions, defining optimum cutting and grazing strategies, defining fertilizer requirements, developing systems for the use of trees as forage and for other uses, and assessing the nutritive or feeding value of tree and shrub species. Areas for further research on these various aspects are suggested*

Résumé *— Les arbustes et les arbres, particulièrement ceux des espèces fourragères, s'emploient de plus en plus comme source stratégique de fourrage de haute qualité à donner au bétail en complément de sa ration alimentaire. L'auteur passe en revue la recherche visant à trouver des espèces qui pourraient, entre autres usages, servir de fourrage. Les chercheurs se sont surtout attardés à évaluer l'adaptation des espèces aux diverses conditions climatiques et édaphiques, à définir les stratégies optimales de rabattage et de pâturage, à établir la fertilisation requise, à élaborer des systèmes dans lesquels les arbres servent de fourrage et ont d'autres usages également et à évaluer la valeur nutritive des espèces arbustives et ligneuses. Il suggère dans quelle direction pousser la recherche sur tous ces sujets.*

Resumen *— Los arbustos y árboles, particularmente las especies leguminosas, se están utilizando cada vez más como fuente estratégica de forraje de alta calidad, para complementar la alimentación de animales de granja. Este trabajo analiza la investigación destinada a identificar especies apropiadas para forraje y para otras aplicaciones múltiples. Se ha centrado la investigación en: evaluar la adaptación de las especies a diversas condiciones climáticas y edáficas, definir las formas óptimas de pastoreo y corte, definir las necesidades de fertilizantes, elaborar sistemas para el uso de árboles como forraje y para otros usos, y evaluar el valor nutritivo o alimenticio de especies de rboles y arbustos. Se hacen sugerencias con respecto a sectores donde se debe efectuar una mayor investigación sobre estos diversos aspectos*

The leaves, pods, seeds, and edible twigs of shrubs and trees have been used as supplementary feed for domesticated animals for centuries. This feed source has been used by browsing animals or through the deliberate cutting of shrubs and trees and supply of forage to free-grazing, tethered, or confined animals. The use of shrubs and trees as a source of forage for domesticated animals has been mostly opportunistic, based on farmers' knowledge that some indigenous shrubs or trees are palatable and have a reasonable or good nutritive value for livestock, particularly during periods of feed shortage. It is only recently that there has been a deliberate policy to plant selected trees and shrubs around houses or on farms to supply feed to livestock and improve animal productivity throughout the year. Usually, the species chosen have other desirable, multipurpose characteristics.

In this context, there is a need to better understand the management, agronomic features, and nutritive value of these shrubs and trees so that the production and use of feed can be more efficient. There is also a need to identify shrub and tree species that are able to maintain a high level of productivity in intensive production systems. The development of intensive uses of shrub and tree forages for animal production is relatively recent in comparison to intensive forms of animal production based on grass and herbaceous legume species. Thus, the scientific knowledge on agronomic factors that affect the productivity of tree and shrub forages is less well known and confined to relatively few species. In addition, the species that have received the most attention are leguminous species, which have shown an ability to remain productive under repeated cutting at frequent intervals, to have good nutritive value, and to be reasonably well eaten by animals. The information provided in this paper will, therefore, refer mainly to comparatively few leguminous shrubs or trees that are commonly used or have a potential for use in more intensive production systems.

Species

There are many desirable agronomic characteristics of shrubs and trees that are relevant to their potential as animal feed. In general, the more important or desirable agronomic features of a species are that it

- be reasonably easily and reliably established,
- exhibit a good competitive ability against weeds (particularly during establishment),
- remain highly productive under repeated cutting or grazing and browsing,
- be well adapted to the particular climatic and edaphic features of the environment,
- require no or little fertilizer,
- be resistant to local pests and diseases,
- have adequate seed production or be reliably vegetatively propagated, and
- have a good nutritive value and reasonable palatability and acceptability to animals.

There has been considerable interest in the Asian region and, more recently, in Africa and tropical America in the selection and evaluation of shrub and tree species, that meet these criteria and have a potential for multipurpose use. Particular interest has been shown in leguminous species that have potential for wood and forage production, and green manuring on degraded or infertile land

(MacDicken 1988) — the better soils and environments are mostly used for cropping.

A wide range of tree species, both leguminous and nonleguminous, has been identified as suitable for feeding to animals in Africa (Le Houerou 1980), Australia (Turnbull 1986, 1987), India (Tejwani 1988), Indonesia (Ivory and Siregar 1984; Soedomo et al. 1986), Nepal (Sapkota 1988), the Philippines (Hensleigh and Holloway 1988), and Thailand (Topark-Ngarm and Gutteridge 1986). Nonleguminous species have mainly been used where they are indigenous and have rarely, if ever, been deliberately planted as sources of forage for livestock. Leguminous trees have been preferred for planting; this may be because they can form an effective nitrogen-fixing capacity through rhizobial symbiosis; thus, these species do not require large inputs of nitrogen fertilizer to sustain high levels of production under repeated cutting. An additional advantage of leguminous species is their high protein content, which is usually the most deficient component of an animal's diet. Thus, research has concentrated on the evaluation of suitable leguminous species and agronomic practices that maximize their productivity.

Brewbaker (1986) has listed a wide range of leguminous tree species that can be used as animal feed. However, most research has been confined to a few species. Genera that have shown promise include *Acacia* (NAS 1979; Turnbull 1987), *Calliandra* (NAS 1983), *Desmodium*, *Gliricidia* (Chadhokar 1982; Falvey 1982; Withington et al. 1987), *Leucaena* (Pound and Martinez-Cairo 1983; NAS 1984), *Sesbania* (Wood and Larkens 1987), and *Prosopis* (NAS 1979). *Leucaena* has received the most attention and is the most widely planted tree species for animal feed; however, it is ill-adapted to acid soils, particularly when associated with high exchangeable aluminium and manganese and low exchangeable calcium, and has suffered recently from severe attacks by the *Leucaena* psyllid, *Heteropsylla cubana*. Because adverse soil conditions are prevalent in Asia, there has been a more widespread evaluation of alternative tree species (Ivory and Siregar 1984; Panjaitan and Blair 1984; Catchpoole et al. 1985; Ivory et al. 1986; Topark-Ngarm and Gutteridge 1986; Bray et al. 1988; Ella 1988; Blair et al. 1989).

Establishment

Shrubs and trees are usually propagated from seed but some species can be reliably propagated from stem cuttings. The seeds of leguminous species usually have a hard seed coat that requires some form of treatment for the imbibition of water and germination. This can include treatment with hot water, chemical agents (acids and alkalis), or mechanical scarification. Some variation occurs between species in the need for scarification and in the most effective form of treatment.

One of the major problems in the establishment of shrubs and trees is competition from weeds. Seedling growth rate is often slow, resulting in high plant mortality. Therefore, there are considerable advantages in germinating seed and raising young plants in a nursery before transplanting to the field. Although the costs are higher, a more vigorous plant can be produced through better nursery care and by using an appropriate strain of *Rhizobium* with leguminous species and a small amount of fertilizer. The trimming of shoots and roots at the time of transplanting reduces transpiration and stimulates root development (Pound and Martinez-Cairo 1983). Following transplanting, such a seedling is better able to compete with weeds. In Asia, most animal producers are small-scale landholders and, therefore, are only interested in establishing small areas of trees for forage production. Local materials, such as bamboo, can be used to make a seedling tube at little cost to a smallholder. Where large areas are to be established, however, this procedure may be logistically and economically unfeasible. In such a situation, direct drilling into a prepared seedbed or into cultivated strips or rows are better than broadcast sowing.

Some species can be vegetatively propagated. *Gliricidia sepium* is usually established from stem cuttings. Studies on the effect of age, diameter, and length of stem cuttings; their position on the parent tree; type of cut; length of storage time; and depth of planting have shown that cuttings should be taken from stems that are at least 6 months old, 0.5–2.0 m in length, and from the lower part of the tree. Stem sections should be planted as soon as possible after cutting (Falvey 1982). Establishing cuttings in a nursery improves the survival rate of stem cuttings. The use of 2,4-dichlorophenoxy acetic acid (2,4-D) and naphthaleneacetic acid (NAA) may improve root development (Kempana and Chandrasekhariah 1959; Kempana et al. 1961; Chaudhuri 1965) and thereby improve survival. Stem cuttings can also be propagated by air layering with the aid of growth regulators (Kempana et al. 1961).

Productivity and management

Agronomic practices and management of shrubs and trees for forage production depend on the type of production system being employed. Major production systems include

- trees planted in single hedgerows (around houses or on the edges of cultivated fields),
- trees planted in multiple rows (widely spaced on uncultivated land with planting on the contour if the land is sloping, or more closely spaced in cultivated fields used for annual cropping (alley cropping) or in sown pasture areas), and
- intensive systems of production (more equal inter- and intra-planting distances at higher plant densities).

The most important factors affecting the productivity of these systems relate to plant density, planting configuration, cutting management (time of first cutting and height, frequency, and season of cutting), and fertilizer use. However, practices that maximize forage productivity may have to be modified to meet other particular purposes of using the trees and shrubs.

Tree plant density

The effect of tree density on leaf and wood yield has not been extensively studied. The majority of plant-spacing studies have been with *Leucaena*. In general, higher densities cause an increase in leaf and wood yield per unit area and a decrease in individual tree yield. Often, yield per unit area has been highest at the highest densities used in experiments and, therefore, few experiments have defined optimum tree densities for maximizing yield per unit area. The highest yields of *Leucaena* have been obtained at 1 tree/m^2 (Castillo et al. 1979), 4 trees/m^2 (Pathak et al. 1980), 6 trees/m^2 (Savory and Breen 1979), 10 trees/m^2 (Relwani et al. 1982), and 13 trees/m^2. Ella (1988) studied the effect of tree density on leaf and wood yield in *Leucaena*, *Gliricidia*, *Sesbania*, and *Calliandra* and found that yield per unit area for all species was highest at the maximum density used, 4 trees/m^2. Hegde (1983) recommended an optimum planting density for *Leucaena* of 10–15 trees/m^2. It is apparent, therefore, that where high leaf yields per unit area are required, tree densities should be high. However, optimum tree densities will depend on rainfall and would be expected to be lower in less humid environments. Dense stands are only suitable for cut-and-carry systems, not for animal grazing.

High plant densities also reduce weed competition, but require much higher initial costs where seedlings are raised in nurseries for subsequent transplanting. Also, Obando (1987) found that *Gliricidia* was able to suppress the growth of weed species through allelopathic effects.

Ella (1988) found that wood yield per unit area of all species increased with increasing density; the leaf/stem ratio increased with increasing density in *Gliricidia* and *Calliandra*, but showed little difference in *Leucaena*. Differences in leaf and wood yields at different tree densities were observed mainly during the wet season; only small differences were observed in the dry season.

In hedgerow situations (e.g., in situ grazing or alley cropping), wide row spacings are required with higher intrarow densities. For *Gliricidia*, there appears to be equal compensation between lower tree productivity and increased plant density within the row over a range of spacing intervals. Kang and Reynolds (1986), as cited by Atta-Krah and Sumberg (1987), found that when within-row seedling spacings varied from 4 to 50 cm in an alley cropping system, the production of *Gliricidia* per unit row length remained relatively constant, although stem diameters were larger with increasing distance between plants.

There has been some research on the interaction between inter-and intra-row spacing on yield per unit area; however, no definitive experiments have examined the effect of plant spacing configurations on tree productivity at constant plant densities. It is, therefore, difficult to define optimum planting configurations and densities for intensive tree-production systems based on existing information.

Cutting management

Cutting management of tree and shrub legumes has been reviewed by Horne et al. (1986). The management factors that can affect tree productivity include age at first cutting, cutting height, cutting frequency, and season of cutting. Most research on cutting management has emphasized the effect of height and frequency of cutting, particularly with *Leucaena*.

Age of first cutting

It has been generally stated that where trees are older at first cutting, higher rates of regrowth will be observed. This would be expected because older trees would have thicker stems, more carbohydrate reserves, and a deeper, more extensive root system. Both Bhumibhamon et al. (1984) and Pathak et al. (1980) concluded that regrowth of *Leucaena* was positively related to basal diameter (stump size).

However, the optimum age of first cutting would be expected to interact with plant density. In addition, certain species (e.g., *Sesbania grandiflora*) have shown poor regrowth following cutting; this may be because the tree is too large at the first cutting.

Ella (1988) examined the effect of age of first cutting (13, 15, 17, 19 and 21 months from planting seed) on the productivity of widely spaced *Calliandra*, *Leucaena*, *Gliricidia*, and *Sesbania*. Increasing plant age at first cutting increased leaf and wood yields over five subsequent harvests in *Leucaena* and *Gliricidia*. A smaller increase was observed with *Calliandra* and there was a slight decrease in *Sesbania* yield. These species have very different rates of early growth and, therefore, were very different sizes at the imposed age of first cutting. Experiments need to be conducted on the time of first cutting in relation to the physiological age of individual species. Other factors requiring consideration are the degree of interaction between age of first cutting and plant density, and the initial loss in production from later cutting in relation to total long-term productivity.

Cutting height

Many studies have examined the effect of cutting height on *Leucaena* yield (Horne et al. 1986). The highest yields have been obtained from cutting heights of 5–300 cm. This is a wide range and suggests that cutting height has a considerable interaction with other factors — plant type or cultivar, plant density, cutting interval, and perhaps environmental factors. In experiments with other tree and shrub species, Siregar (1983) found the optimum cutting height for *Flemingia congesta* and *Calliandra calothyrsus* was 1 m; Lazier (1981) found that cutting heights of 25 and 50 cm for *Codariocalyx gyroides* gave higher yields than cutting at 5 cm; and Munegowda and Krishnamurthy (1984) found that a cutting height of 50 cm for *Sesbania aegyptica* (syn. *S. sesban*) gave higher yields than higher cutting heights.

Because of the conflicting results and for convenience, a standard cutting height of 1 m is often used to compare species performance (Catchpoole et al. 1985; Panjaitan 1988; Ella 1988; Bray et al. 1988). More research is required to better define optimum cutting heights for promising species in relation to species differences in plant growth habit and other management or cultural parameters.

Cutting frequency

Studies concerned with defining an optimum cutting interval for *Leucaena* have given extremely variable results (Horne et al. 1986). This is partly because of the strong interaction with other cultural factors as well as the problem that measured yield has referred both to leaf only and total (leaf + stem) yield. Generally, total yield is increased by longer cutting intervals; however, because of a general decrease in the leaf/stem ratio with longer cutting intervals, there is a less pronounced effect of cutting interval on leaf yield. Both Catchpoole et al. (1985) and Ella (1988) have studied the effect of cutting frequency on the leaf and stem production of *Leucaena*, *Calliandra*, *Gliricidia*, and *Sesbania*. Catchpoole et al. (1985) found that cutting frequency, which varied from 7 to 18 weeks, had little effect on leaf production, except for a slight decrease in *Calliandra*. Longer cutting intervals increased wood production and total yield in all species. At a range of lower plant densities, Ella (1988) found that increasing the cutting intervals from 6 to 12 weeks increased leaf yield in *Leucaena*, *Gliricidia*, and *Calliandra* in some wet-season harvests; there was no effect on cutting frequency with *Sesbania*. Wood and total yields increased substantially in all species with longer cutting intervals.

It would seem, therefore, that cutting interval will be dictated by the purpose for using trees. In humid climates, where the major emphasis is on leaf production for feeding to animals, shorter cutting intervals (6–10 weeks) will be preferred — this will produce feed of a higher nutritive value with little loss in annual production. Where wood production is also an important output from the system, however, longer cutting intervals (10–14 weeks) would be appropriate. These regrowth intervals would approximate to regrowth heights of 1.5 m for leaf production or 2.5 m for leaf and wood production (Catchpoole et al. 1985). In less humid environments, longer cutting intervals may be required.

Season of cutting

Where there are distinct wet and dry seasons, some consideration has to be given to timing and type of defoliation. If the dry season is prolonged, this will be a more critical period for feed supply for animals. Timing of cutting may be determined by what can be done to use the surplus production in the wet season for dry-season feeding and dry-season management. Strategies for seasonal feed management may include carrying over leaves on trees into the dry season, with the successive cutting of branches during the dry season. This may be combined with more regular, complete defoliation during the wet season. Other possibilities include storing dried feed or producing silage (Kass and Rodriguez 1987) in the wet season. There has been little research on these aspects of feed utilization in relation to developing a complete cutting-management strategy.

In grazed situations, research has demonstrated the value of deferring the grazing of tree legumes (protein banks) for dry- or winter-season grazing (Jones 1979; Bamualim et al. 1980), when the protein component of the animal diet is more critically deficient.

Fertilizer requirements

There is little use of fertilizers for forage production in smallholder systems in Asia. This is because of the generally extensive nature of the forage-production systems used, the relatively high input cost of fertilizer, the relative unimportance of animal production compared with crop production, and a general lack of knowledge of the farmer about the nutrient requirements for forage production. Therefore, tree species that are adapted to the particular soil conditions have to be selected. It is known, for example, that *Leucaena* is only well adapted to more neutral or alkaline soils with high Ca availability. Therefore, it is more appropriate on acid soils, particularly soils with a low Ca supply and a high Al saturation, to select species that are well adapted to these conditions rather than use large quantities of lime to ameliorate the soil conditions so that they are suitable for *Leucaena*.

Despite the selection of generally better adapted species for particular soil conditions, specific nutrient deficiencies can still be identified. The use of N-fixing tree legumes removes the need for N fertilizer. However, Ca and P are often insufficient for tree growth on the infertile soils generally used for forage production. Most research on fertilizer requirements of tree legumes has been with

Leucaena. The largest growth responses in *Leucaena* have been obtained from Ca and P application, with some responses to S, and no responses to K (Pound and Martinez-Cairo 1983). On acid soils, significant responses have also been obtained from lime pelleting seeds and fertilizer application of P, S, Ca, and Mo at planting. Where trees are planted in rows, banding of P is more efficient than broadcast application and on acid soils rock phosphate will provide a cheaper, longer-term supply of P than superphosphate.

The application of fertilizer at planting will enhance the establishment and efficiency of the *Rhizobium* symbiosis. More rapid, early growth rates for many tree legumes species have been obtained from P and Ca application on infertile, acid soils in Indonesia (Bray et al. 1988; Panjaitan 1988).

Because tree legumes can provide valuable, high-quality forage to the diet of livestock, there is justification for using fertilizer if needed. In intensive cutting systems, there is a large demand by the plants for soil nutrients. Fertilizer inputs may be required to sustain high levels of forage production. There is a need, therefore, to better characterize the nutritional requirements of a range of promising tree legumes under intensive repeated cutting as well as define the soil factors that limit their growth and edaphic adaptability.

Plant characteristics and use

Protein banks or intensive feed gardens

Trees and shrubs can be grown in dense plantings in single or multiple rows to produce high-quality forage. This forage can be harvested regularly and fed to animals as a supplement to poorer quality forage or crop residues (Manidool 1984; Ivory and Semali 1987). In such systems, perennial tree species are required that can maintain high regrowth rates, high leaf production, high leaf nutritive value, and strong perenniality under repeated cutting and possibly compatibility with companion forage species.

Highly productive grasses can be combined with trees in dense plantings. In West Africa, *Gliricidia* and *Leucaena* were planted in alternate rows with a 2.5 or 4 m interrow spacing and two or four rows of grass planted between the trees (Atta-Krah and Sumberg 1987). With frequent cutting, these systems annually produced 20 t/ha of mixed grass–legume forage. Several studies in Indonesia have also examined the productivity of densely planted tree–grass systems for intensive cutting. Ella (1988) studied the interaction of tree species, tree density, and cutting interval on companion grass production (*Panicum maximum*). Up to 15 t dry matter/ha of grass and tree forage was produced over 8.5 months. In the dry season, density and cutting interval had little effect on grass production; in wet season harvests, however, grass yield was inversely related to tree leaf yield, particularly at higher tree densities. Horne (1989) also studied the effect of various cutting strategies that manipulated the *Leucaena* canopy structure and the relationship of this to the production of *Leucaena* and the two interplanted grasses (*Pennisetum purpureum* and *Setaria splendida*). *Leucaena* mixed with *P. purpureum* gave a lower total yield than grass alone; however, when mixed with *S. splendida*, there was a higher total yield. Higher yields of *Leucaena* in mixtures were given with higher cutting heights of *Leucaena* with *P. purpureum* but lower cutting heights with *S. splendida*.

Tree legumes have also been combined in more complex systems. Nitis et al. (1987) used a three-level, forage-production system that combined grasses and herbaceous legumes at ground level, a tree legume (*Gliricidia*) at the intermediate level, and large trees at the highest level.

Trees can also be used for more strategic special purposes. Some species, particularly *Sesbania*, *Cajanus*, and *Codariocalyx* spp., have shown high early growth rates but poor perenniality under repeated cutting. These species are potentially useful when planted in cropping systems late in the wet season to produce dry-season feed. *Sesbania grandiflora* is used for this purpose in rice-cropping systems in East Java, Indonesia.

Alley cropping

In alley cropping systems, tree legumes are usually used for green manuring. Therefore, leguminous trees are required that produce leaves with a high nitrogen content, rapid rate of regrowth with a high leaf/stem ratio, a dense, erect canopy and deep root system (to minimize competition with the crop), and leaves that have moderate rates of decomposition.

In tropical soils, leaf material is rapidly decomposed. Wilson et al. (1986) found that with an annual rainfall of 1 200 mm, 50% of the nitrogen in *Gliricidia* leaves was decomposed in 3.6 weeks; with 2 400 mm/year, it was decomposed in 1.6 weeks. Thus, it is difficult for a crop to use fully this N source if tree leaf is applied before planting, although incorporation and banding provides a more efficient recovery than leaves that are surface broadcast. It is possible, however, to include livestock in this system — the animal retains little of the ingested N and most can be returned to the crop either from in situ grazing before planting or as animal manure from feeding pens. This may improve the N economy of the crop–animal system as N release from manure is slower and more attuned to the needs of the growing crop. Catchpoole (1989) showed that little of the nitrogen contained in ^{15}N-labeled *Gliricidia* and *Leucaena* leaves fed to goats was retained and 45 and 10% of ^{15}N was recovered by grass from excreted urine and dung, respectively. There is a need, therefore, to consider the opportunity costs of using tree foliage in alley cropping systems solely as an animal feed with manure returned, solely as a green manure, or in different proportions for each purpose. Tree leaves in alley cropping systems can also be used as a supplement for animals grazing crop residues between successive crops.

Forage trees can also be combined with perennial tree crops. In the Philippines, Moog (1986) found that when *Leucaena* planted in hedgerows 2–3 m apart (with fruit trees in the alleys) was harvested every 40–60 days, the system produced more than enough feed for 20 cattle from 2 ha.

In situ grazing

Tree legumes have been planted in widely spaced rows in grass pastures for both beef (Jones and Bray 1982) and dairy (Plucknett 1970; Stobbs 1972) production. The most widely used tree species in grazing systems is *Leucaena* (Jones and Bray

1982); *Gliricidia* has been used for dairy production (Chadhokar and Lecamwasam 1982; Chadhokar 1983). Continued production from such systems depends on a rotational system of grazing that allows rapid tree regrowth. Thus, tree species must tolerate complete defoliation and damage from grazing animals as well as sustain rapid rates of regrowth from numerous growing points on the remaining stems following grazing. Leaves should have a high N content, high nutritive value, be readily eaten by animals when fresh, and have good leaf retention for deferred grazing, particularly in the dry season.

Seed production

Although seed production is an important prerequisite for maintenance and expansion of planted areas of trees and shrubs, except for species that are readily vegetatively propagated, there has been little research on this aspect. There is considerable variation in the amount of seed produced by tree species and, whereas some species produce seed throughout the year (e.g., *Leucaena*), others produce seed at restricted periods because of photoperiod or dry-season stimuli (e.g., *Gliricidia*). Obviously, the production of adequate, good-quality seed is a desirable attribute for a tree species used for forage or multipurpose uses.

For many species, actual harvested yields of seeds are considerably lower than potential seed yields because of the inaccessibility of higher branches or through seed loss from the shattering of pods. In addition, for some shrub and tree species, seed quality may be poor during the wet season because of susceptibility to fungal diseases.

Seed storage is another aspect of seed production that has received relatively little attention from research on shrub and tree species. In general, it is known that seed keeps longer if the moisture content is reduced to a low level after harvest and the seed is stored in a dry environment.

Nutritive value

There is extreme variability in the nutritive value of the shrub and tree species used as livestock feed. This variation is due to greatly varying inherent nutritive values between species as well as the variation found within species because of differences in plant parts, age of tissue, and the soil and climate in which the plant is growing. The nutritive value of forage is a function of its digestibility, chemical (mineral) composition, and presence of toxins or antinutritive factors. Discussion here will be confined to nutritive value; a subsequent paper (Devendra, this issue) discusses feeding value and the use of trees and shrubs by livestock.

Digestibility

Considerable variation in proximate analyses and digestibility have been recorded for tree species used for animal feeding (Gohl 1981; Bulo et al. 1985; Brewbaker 1986; Vercoe 1987; Goodchild and McMeniman 1987; Little et al. 1989). Vercoe (1987) found that in vitro dry matter digestibility (IVDMD) varied from 16.9 to 66.9% and crude protein from 8.6 to 22.6%. Brewbaker (1986) listed a wider range of crude protein contents (6.9–33%) and Little et al. (1989) found a range of 10–29% for N tree legume species. Bulo et al. (1985) found that the IVDMD of leaf and edible stems of 12 shrub or tree legumes varied from 36.0 to 63.4% and 34.5 to 58.2%, respectively; crude protein varied from 11.3 to 30.6% and 9.4 to 18.1%, respectively. Panjaitan (1988) found that the crude protein content of leaves tree legumes grown at four sites in Indonesia varied from 22.5 to 29.4% in the wet season and from 19.4 to 28.8% in the dry season. *Leucaena* cultivars had higher crude protein contents during the dry season; however, *Gliricidia*, *Calliandra*, *Sesbania grandiflora*, *S. sesban*, and *Albizia falcataria* had higher crude protein contents during the wet season. The crude protein content of N-fixing leguminous trees are usually high compared with mature grass fodder and crop residues; even nonleguminous trees can have reasonable protein contents (Le Houerou 1980; Soedomo et al. 1986; Little et al. 1989).

Fruits and pods of leguminous species can also have a high protein content (10–20%) (Brewbaker 1986; Goodchild and McMeniman 1987). Generally, pods have a lower crude protein content but a higher organic matter digestibility than leaves. Milled *Acacia* pods with seeds have provided a supplement of similar value to maize bran (Gohl 1981).

Among leguminous species, phyllodinous leaves tend to have higher crude fibre and lower crude protein, phosphorus, and organic matter digestibility than bipinnate leaves (Brewbaker 1986; Goodchild and McMeniman 1987). Compared with other sources of forage, trees generally have a high ether extract and moderate ash content; nitrogen-free extracts are generally lower (Brewbaker 1986; Goodchild and McMeniman 1987).

Cutting management and soil fertility status will also affect the nutritive value of trees. More frequent cutting will reduce fibre content and increase crude protein (Chadhokar 1982) and IVDMD. Any nutrient deficiencies in the soil will decrease the protein content of leguminous species. Thus, tree forage can provide a valuable source of supplementary protein to the diet of animals and can also improve the overall use of forages. For example, the addition of energy sources, such as cassava peel and cassava tubers, raised the dry matter digestibility of *Gliricidia* from 54–57% when fed alone to 70–74% in the mixture (Ademosum et al. 1985). Conversely, the addition of legume leaves can increase the digestibility of low-quality forages. It has been generally recommended that tree forage should make up 30% of the total animal diet if its higher protein content is to be used most effectively.

Chemical composition

Tree forage can also provide an important source of nutrients for the animal's diet. Vercoe (1987) analyzed the foliage of 23 species of trees used for livestock feeding or browsing in Australia, most of which were leguminous species, and found considerable variation in their chemical composition: P, 0.05–0.18%; K, 0.41–1.78%; Ca, 0.29–3.52%; S, 0.21–1.13%; Na, <0.01%–0.41%; Mg, 0.21–0.62%; Cu, 4–152 ppm; Zn, 22–123 ppm; Mn, 30–917 ppm; Al, 26–325 ppm; B, 16–59 ppm; Ti, 0–9 ppm. Brewbaker (1986) also listed chemical analyses for P, Ca, Mg, K, and Si for the edible parts of 23 leguminous tree species used for animal feeding. Higher upper values were recorded for P and K, lower upper values for Ca, and lower values for Mg compared with the values of Vercoe (1987). Little et al. (1989) measured the concentration of essential dietary mineral nutrients in 11 species of tree legumes and 9 species of nonleguminous trees or shrubs used for feeding ruminant animals in five regions of Indonesia. Wide ranges of essential minerals were also recorded in these feeds. They concluded that low concentrations of Na and Cu were widespread, marginal levels of P and Zn occurred with moderate frequency, and potential deficiencies existed for Co, Se, and Mo. Vercoe (1987) found that all species satisfied the minimum animal requirements for Ca (0.18%) and S (%); however, each species tested was found to have low concentrations of at least one essential element for animal growth. The most generally deficient element was P; it was below the estimated requirements for sheep and cattle (%) in 86% of species tested. Sodium values were low, as also found by Bulo et al. (1985) and Little et al. (1989) for other tree species. *Leucaena* has low levels of both Na and I (Jones 1979).

The nutrient values listed by Vercoe (1987), Brewbaker (1986) and Little et al. (1989) are for species growing in many different environments and do not necessarily reflect inherent species differences. Where the chemical composition of leaves and edible stems of 12 tree legumes were compared at the same site, considerable variation was found between species (Bulo et al. 1985). Nutrient concentrations were generally higher in leaves than in edible stems, except for *Desmodium salicifolium* and *Codariocalyx gyroides*, and for sulfur, which showed inconsistent results. Jones (1979) also observed considerable variation in nutrient concentrations in various plant parts for *Leucaena*.

The growing interest in tree legumes as sources of fodder has led to a more intensive examination of their digestibility and mineral composition. There is now a need to form a comprehensive data base of chemical analyses of tree species with potential as animal feeds. Adequacy ratings can then be established for individual species for the elements essential to animal growth.

Toxins and antinutritive factors

Many tree species are not useful or have problems associated with feeding to livestock. In addition to low digestibility, some tree species have low palatability or acceptability to livestock or contain toxins. High levels of phenolic compounds (tannins) in many tree species have been implicated as reducing palatability or acceptability (Hegarty et al. 1986; Brewbaker 1986), as well as strong odours in crushed leaves, such as in *Cassia* spp. and *Gliricidia*. The wilting or drying of tree fodders has been a method used by farmers to overcome or reduce palatability or toxicity problems in some tree species.

Several toxic compounds have been identified in tree species, such as robitin in *Robinia* and cyanogenic glucosides in *Acacia* spp. (Maslin et al. 1987). Some compounds that have caused toxicity problems, such as mimosine in *Leucaena*, have been found to be detoxified by specific rumen bacteria (Jones 1985). It may be possible to find other rumen organisms that can degrade phenolic compounds in tree species that are very productive and adapted to adverse soil conditions but have low palatability.

Toxic levels of particular elements can also cause problems with animal health. Vercoe (1987) found high contents of some trace elements in *Acacia* spp. For example, Cu concentrations were high for some species. Copper concentrations as low as 40 ppm can poison sheep if levels of Mo and S are low (Underwood 1981); cattle are more tolerant.

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Discussion

Session I was concerned with the diversity of shrubs and tree fodder resources and their characteristics. Three papers were presented.

The first paper, by Dr Blair, discussed the diversity and potential value of shrubs and tree fodders. Dr Blair pointed out that the potential resource is very large in terms of the number of species that have the ability to produce sustained biomass; however, such diversity is difficult to evaluate. There is not only taxonomic diversity but also extreme ranges in growth habits, form, and response to cutting, soil conditions, and the presence or absence of grasses. The requirements for a tree to produce useful supplementary fodders were advanced.

Discussion centered on the benefits of using alley cropping to produce green foliage for ruminant feeds rather than for green manure. It was pointed out that the excreta of animals on supplemental diets gave better plant growth responses than that from animals on unsupplemented, low-quality diets.

Questions were also raised on the criteria for evaluating trees, tree–grass interactions, sources, and screening of new plant collections. Potentially important fodder trees must benefit the plant underneath as well as serve other functions, otherwise farmers will not be interested in them. In semi-arid and arid environments, fodder trees were considered useful not only as feed supplements but also as a major, and sometimes sole, component of the diet. In these circumstances, fodder trees are acceptable, even if they are of lower quality.

Dr Topark-Ngarm presented the second paper on shrubs and tree fodders in farming systems in Asia. The term "living fence," one of the methods of managing fodder trees, was used in a very wide context, meaning virtually any wayside, nonplantation establishment. This presented a practical constraint concerning the distance between the trees and the animals. Various systems of alley cropping were also described.

Evidently, there are particular combinations of crops and shrubs that are more successful than others, and certain crops will not perform well in combination. This was confirmed by the results from Nigeria on the performance of the cowpea in alley-cropping systems.

The third paper, presented by Dr Ivory, focused on the major characteristics, agronomic features and nutritional value of shrubs and tree fodders. Dr Ivory pointed out that although a number of nonlegumes have local uses as fodder trees, none have been developed for wide acceptance. He provided a very useful background on the factors that affect the desirability of plant species, as well as their establishment, productivity, and management.

The latter included tree plant density, cutting management, age of first cutting,

cutting height, cutting frequency, season of cutting, and fertilizer requirement. Emphasis was also given to leaves and edible stems of shrubs and trees that can be used in different feeding systems. There was a considerable need for more information on the chemical composition of leaves of different species.

Seed production was considered a major constraint to expanding the planted area of shrubs and trees. The problem of establishing shrubs and trees on infertile soils was also discussed.

Session II

Use by Farm Animals

The use of shrubs and tree fodders by ruminants

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***Abstract** — The potential value of shrub and tree fodders is discussed with reference to the range of feeds available and extent of their current use by ruminants in developing countries. The discussion indicates that most of the information on hand relates to agronomic characteristics, rates of productivity, and chemical composition. The information on use by ruminants is generally sparse. Currently, shrub and tree fodders have the greatest value in extensive systems in semi-arid and arid regions, especially for small ruminants. By comparison, fodders from trees are used as supplements for large ruminants. The most widely used feed sources are* Acacia *spp., cassava leaves (*Manihot esculenta*),* Erythrina variegata, Ficus *spp.,* Gliricidia *spp.,* Leucaena leucocephala, *and* Sesbania grandiflora. *Research and development programs need to address much more thoroughly patterns of use by individual ruminants and productivity, including feeding behaviour, palatability, management systems, deleterious principles, and effects on animals. To develop and establish intensive feeding systems with shrubs and tree fodders in developing countries, these and other issues urgently need attention.*

***Résumé** — L'auteur traite de la valeur potentielle des arbustes et arbres fourragers, prenant pour toile de fond toute la gamme des fourrages dans les pays en développement et leur exploitation actuelle par les ruminants. Il indique que presque toute l'information disponible concerne les caractéristiques agronomiques, les taux de productivité et la composition chimique. Il y a peu de données sur l'exploitation par les ruminants. En ce moment, les arbustes et les arbres fourragers sont surtout exploités par les petits ruminants dans les systèmes extensifs des régions arides et semi-arides. Ils servent de complément à la ration alimentaire des gros ruminants. Les sources de fourrage les plus utilisées sont* Acacia *spp., les feuilles de manioc (*Manihot esculenta*),* Erythrina variegata, Ficus *spp.,* Gliricidia *spp.,* Leucaena leucocephala *et* Sesbania grandiflora. *Les programmes de recherche et de mise en valeur doivent étudier plus à fond l'utilisation de ces végétaux par chaque ruminant et leur productivité, y compris la façon dont ces animaux se nourrissent, l'appétibilité et les systèmes de gestion, les principes délétères et les effets sur les animaux. Il est urgent de se pencher sur ces questions si l'on veut établir des systèmes d'alimentation intensifs.*

***Resumen** — Se trata el valor potencial de arbustos y árboles forrajeros con relación a la proporción de recursos alimenticios y el grado de su utilización actual por rumiantes en los países en desarrollo. El estudio indica que la mayor parte de la información disponible se relaciona con las características agronómicas, porcentajes de productividad y composición química. Por lo general, la información que se posee sobre el uso por los rumiantes es escasa. En la actualidad, los forrajes de arbustos y árboles ocupan el valor más alto* *en los sistemas extensivos de las regiones áridas y semiáridas, especialmente para rumiantes pequeos. En forma similar, el forraje obtenido de los árboles se utiliza como pienso suplementario para grandes rumiantes. Las fuentes alimenticias que se utilizan más ampliamente son* Acacia *spp., hojas de mandioca* (Manihot esculenta), Erythrina variegata, Ficus *spp.*, Gliricidia *spp.*, Leucaena leucocephala *y* Sesbania grandiflora. *Los programas de investigación y desarrollo deben abordar mucho más minuciosamente los patrones de utilización de cada rumiante y la productividad, inclusive el hábito alimentario, el gusto, los sistemas de explotación, los factores nocivos y los efectos en los animales. Estos y otros problemas necesitan urgente consideración para poder desarrollar e implantar los sistemas de alimentación intensiva con rboles y arbustos forrajeros en los países en desarrollo.*

Shrubs and tree fodders are a particularly neglected, inadequately understood aspect of the feeding systems of ruminants (buffaloes, cattle, goats, sheep, and camels) in developing countries. There are three main reasons for this. First, feeding systems for ruminants are essentially conventional and have evolved in tandem with approaches and methods developed in mainly temperate environments. In these environments, mainly grass is fed to meat- and fibre-producing ruminants; dairy animals receive, in addition, a concentrated supplement. Second, limited information exists on the potential and nutritional value of their wider use in feeding systems for ruminants. Third, the development of innovative feeding systems and demonstration of practical value to support animal production systems in the climatic extremes of the arid and wet regions is relatively recent and is justified by the need to ensure increased productivity from animals in these climates (Devendra 1987b).

In recent years, there has been a growing trend in many regions throughout the developing world to identify potentially important feed sources among shrub and tree leaves and to explore possibilities of including them beneficially in ruminant diets. The drive toward these goals has been promoted by severe feed shortages, severe and prolonged drought periods, continuing low per-animal performance, mortality, and uneconomic production. Curiously, farmers have traditionally used these sources to feed their animals; this use was based on experience and convenience, and was regarded as a practical means of rearing animals. The realization that there was considerable diversity and availability of shrub and tree fodders in developing countries was an important development. It justified giving more emphasis to include shrub and tree fodders in ruminant feeding systems. Additionally, using such fodders reduces cost of production.

This paper reviews in some detail the current understanding of the potential of shrub and tree fodders for use by ruminants. Additionally, this paper refers to potentially important feeding and development strategies that could increase the use of these feed resources and benefit the development of ruminant animals.

Animal resources

It is appropriate to keep in perspective the importance and extent of ruminant animals in the developing world. A wider reference to herbivores is more relevant because many of these species commonly use shrub and tree fodders. The diets of small ruminants and camels consistently contain these feed materials much more than the diets of buffaloes and cattle. However, not enough is known about patterns of use, animal performance, and more intensive systems of production.

Table 1 presents the type and magnitude of the animal resources in the developing countries. Developing countries are home to the vast majority of the world's buffaloes, camels, asses, and goats; cattle and sheep are in a lesser majority. All the meat and milk from buffaloes, and about 93% of the world output of goat meat and 55% of the total goat milk output are produced in the developing world.

Unfortunately, limited statistics are available on the contribution of herbivores to draft power. Buffaloes, cattle, asses, camels, horses, and mules are widely used throughout the developing countries for draft power. Drafting duties range from a wide variety of ploughing operations to transportation, but little is known about this contribution, its effects on crop production, and how potential increases in draft power will affect farming systems. FAO (1981) calculated that the power inputs in developing countries would have to increase annually by 2.3% to achieve an overall annual agricultural growth rate of 3.4% until the year 2000. This would involve an overall increase of 15% in the number of draft animals or a 400% increase in the number of tractors. The latter increase involves considerable capital expenditure, which may not be easily available. Therefore, the importance of draft animals and their contribution to agriculture and farming systems are likely to increase in the future.

Among ruminants, from 1975 to 1985, goat and sheep populations grew the fastest, followed by cattle. Over the same period, the buffalo population was static and, among herbivores, camels and mules showed the highest annual growth rates. Among nonruminants, the chicken population grew quickest, followed by the pig and duck populations. It is interesting that, among the herbivores, the neglected species (goats, camels, and mules) had the highest annual growth rates.

Between ruminants and nonruminants, development programs have generally concentrated on dairy cattle for daily milk production, a sure means of collecting daily revenue. Production technology from industrialized countries is readily

Table 1. Animal resources in the developing countries.

Species	Population (×10^6)[a]	Annual rate of growth (1975–1985, %)
Herbivores		
Buffaloes	137.7 (99.5)	Static
Cattle	855.0 (67.2)	1.2
Goats	463.2 (94.1)	1.5
Sheep	601.2 (52.5)	1.4
Asses	38.8 (95.8)	Negative
Camels	17.2 (98.9)	2.8
Horses	42.6 (65.4)	0.8
Mules	14.7 (97.4)	2.9
Nonruminants		
Chickens	4 872.0 (54.6)	3.2
Ducks	158.0 (81.0)	2.4
Pigs	486.9 (59.2)	2.6

Source: FAO (1977, 1985, 1986).

[a] Values in parentheses represent species population as a percentage of world population.

available in this field. Dairy farming is an important means of promoting social and economic change, as well as the pace of rural development.

Permanent pastures, forests, and woodlands

It is impossible to quantify production because of inadequate statistical data on the extent of the contribution from shrubs and trees producing fodders of potential feeding value to ruminants. It is relevant, however, to monitor the availability and distribution of permanent pastures, forests, and woodlands — these do provide variable sources of feed supplies for ruminant animals.

Table 2 summarizes the extent of available permanent pasture and land under forests and woodlands; corresponding magnitudes of the ruminant livestock units available are also given. Of particular significance in Table 2, is the marked imbalance between the total ruminant livestock units and available permanent pastures in Asia and the Far East compared with the other regions. It is in this region, including centrally planned economies, more than any other, that there is an acute feed shortage for ruminants. Continuing low per-animal performance is the rule rather than the exception. The importance of making maximum use of all available feed resources thus assumes far greater importance in this situation.

Forests and woodlands are included in Table 2 to emphasize the potential of the herbage available under these perennial tree crops, including the use of some of the more important leaves. These feed resources have not been adequately used in the past because of the lack of an adequate methodology for their integration. Such a methodology should involve an appropriate choice of species, the objectives of production, and ensure a high productivity from the land as a result of the combined thrust of both animal and crop. In South Asia, Southeast Asia, and the

Table 2. Extent and distribution of permanent pastures, forests and woodlands, and ruminant livestock.

Region	Permanent pastures ($\times 10^6$ ha)[a]	Forest and woodland ($\times 10^3$ ha)[a]	Ruminant livestock units ($\times 10^6$)[b]
Developing market economies			
Africa	631.2	645.7	138.4
Asia and the Far East	109.8	220.5	356.3
Latin America	512.7	928.8	253.2
Near East	267.6	95.2	67.0
Total	1 521.3		814.9
Asian, centrally planned economies	409.8	188.6	100.5
Total, developing countries (A)	1 931.1	2 078.8	915.4
World total (B)	3 170.8	4 086.6	1 319.6
A as % of B	60.9	50.9	69.4

Source: FAO (1986).

[a] 1985 data.

[b] Conversion factors: buffalo, 1.0; cattle, 0.8; goats and sheep, 0.1.

Pacific Islands, for example, there is about 20×10^6 ha of land under tree crops. If half of this area is used by animals, the number of animal equivalents that can be carried, and the productivity from them, assume considerable magnitude (Devendra 1987a).

Shrub and tree fodders as feed resources

The range of feed materials from shrub and tree fodders in the developing countries is enormous. A feature about this diversity, however, is that some materials have been more widely used than others and few programs perform large-scale screening and selection of potentially important shrubs and trees. The reasons for the restricted choice are unclear, except that where fodder trees have been grown, they have tended to be leguminous — their use has often been triggered by a demonstration of benefits other than animal feed.

Table 3 lists the commonly used shrub and tree fodders in the developing world. The list is not exhaustive, but focuses on those feeds that have recently been incorporated into ruminant feeding systems. Of the 13 feed sources listed, *Acacia* spp., *Ficus* spp., *Manihot esculenta* (cassava), *Erythrina* spp., *Gliricidia* spp. (gliricidia), *Leucaena leucocephala* (leucaena), and *Sesbania* spp. are widely used.

Browse is a term referring to the tender shoots, twigs, and leaves of shrubs and trees. They form an important component of the diet of especially goats, sheep, and camels; to a much lesser extent, buffaloes and cattle. Goats depend greatly on browse to meet its feed requirements throughout Asia, Africa, the Near East, and Latin America (Devendra and Burns 1983). Recently, the importance of browse has

Table 3. Important shrub and tree fodders used by ruminants in developing countries.

Common name	Botanical name
Acacia	*Acacia catechu*
	Acacia nilotica
	Acacia siberiana
Cassava	*Manihot esculenta*
Calliandra	*Calliandra calothyrsus*
Erythryina	*Erythryina variegata*
Ficus	*Ficus exasperata*
Banyan	*Ficus bengalnensis*
Peepul	*Ficus religiosa*
Gliricidia	*Gliricidia sepium*
	Gliricidia maculata
Jackfruit	*Artocarpus heterophyllus*
	Azadirachta indica
Lebbeck	*Albizia lebbeck*
Leucaena	*Leucaena leucocephala*
Mesquite	*Prosopis juliflora*
	Prosopis glandulosa
Pigeon pea	*Cajanus cajan*
Sesbania	*Sesbania grandiflora*
	Sesbania sesban
Tamarind	*Tamarindus indica*

been increasingly recognized and has, in fact, been the subject of an international conference (Le Houerou 1980a).

One observation about browse and tree leaves is that the information on their nutritive value is scattered and not as thorough as the more traditional feeds (NRC 1981). These also include a reference to mineral and vitamin content as well as deleterious principles. Recent investigations on macro and micro mineral content suggest that in general tree leaves contained higher calcium content than common fodders (Murugan et al. 1987).

The importance of browse in the diet of goats and, to a lesser extent, sheep is reflected in reports from Africa, Latin America, and Australia. In Northern Africa, browse forms 60–70% of rangeland production and 40% of the total availability of animal feeds in the region. The annual production is about 1.5 kg dry matter (DM)/ha per millimetre of rainfall; of this, 50% is consumed (Le Houerou 1980b). Browse is also a component of alley cropping (Sumberg 1984).

The value of shrub and tree fodders for ruminants is greatest in the more extensive systems in the arid and semi-arid regions typical of most parts of the Sahel, the Near East, and the northern parts of Pakistan, India, and China. It is also important in feed-deficit situations such as in India and Pakistan where the available feed resources are not able to meet the annual feed requirements of the total animal resources. In the arid Bikaner district of Rajasthan in northern India, for example, the vegetation cover is only 2.1% around the villages; here, *Prosopis spicegera* yields 512 kg fodder/ha (Skerman 1977).

In India, from 1970 to 1984, feed deficits have dropped from 37.6 to 32.5% for metabolizable energy and from 61.9 to 54.0% for digestible crude protein (Reddy 1987). This is because of improved feeding systems, more efficient use of available feeds, and increasingly intensive systems of production. Further improvements in this direction are likely, and Reddy (1987) has suggested that many more nonconventional feeds can be used to advantage, further reducing feed deficits.

Use by ruminants

Browse

Although the potential of browse is widely known, remarkably, there is an extreme paucity of information on its use by ruminants. A review of the available literature suggests that the bulk of the work on browse is essentially agronomic, in which types and availability of browse, rates of productivity, and biomass structure have been the main considerations. Associated with these studies, there has been limited work on chemical composition, nutritional value, and intake, with extremely limited or no work on palatability, use, and animal performance.

Thus, a review of browse in the nutrition of livestock in Africa (Otsyina and McKell 1985) indicated that the potential of shrubs was being recognized but that there was a need for more research into ways of managing browse to balance forage quality and quantity between productivity and stability, and between grass and browse. Otsyina and McKell (1985) recommended inter alia identification of superior browse species with regard to productivity, nutritive value, and persistence under grazing by livestock; development of methods for establishing desirable

Table 4. Proportions (%) of various forage classes in the diets of sheep and goats in northern Kenya.

Species	Trees	Shrubs	Dwarf shrubs	Herbs	Grass
Sheep	2.6	6.7	23.7	29.6	36.9
Goats	14.9	15.0	22.5	22.0	25.0

Source: Field (1979).

browse species with grasses in mixed plantings; improvement of management practices of established and native pastures containing both browse and grass species; and documentation of characteristics useful for improving shrublands for different livestock in different seasons.

The limited work on browse that has been reported refers mainly to goats and sheep. In the arid zones of Mexico, observations on 1728 goat bites in a mixed brush grass – forb community revealed that 83% of bites were on browse and forbs and 17% were on grass (Carrera 1971). It appears that the higher nutritive value of some browse accounts for a greater net daily intake of nutrients by goats than by cattle or sheep (Short et al. 1973; Cardova and Wallace 1975; Rector and Houston 1976). By comparison, in Australia, Wilson et al. (1975) used oesophageal fistula to study the food preferences of captive feral goats compared with sheep at three grazing pressures (0.5, 0.25, and 0.17 animals/ha). At low stocking rates, sheep ate 80% herbs and 20% browse; goats ate 20% herbs and 80% browse. At medium and high stocking rates, availability of herbs governed intake. Goats tended to select diets with appreciably higher nitrogen contents than did sheep; however, in vitro digestibility of the nitrogen was not always high.

Recently, dietary selection of goats and sheep in deciduous woodland in northeastern Brazil has been studied. During the dry season (May–December), sheep and goats selected similar diets. During the wet season (January–April), sheep selected mainly grasses and forbs, and goats rapidly shifted among grasses, forbs, and browse (Pfister and Malechek 1986).

The work of Field (1979) clearly shows that goats selected shrubs and tree fodders much more than sheep, who favoured herbs and grasses (Table 4). The upper limits of the inclusion of browse in the diets of goats and sheep are uncertain. Current evidence suggest that these proportions are about 30% in sheep and 85% in goats.

Forage supplements

The greatest value of the forages from shrubs and especially trees is their role as diet supplements (Fig. 1). This role relates to their supply of dietary nitrogen, energy, minerals, and vitamins. In many parts of the tropics, there are regular feed shortages and droughts. In such conditions, subsistence feeding, mainly on cereal straws, results in reduced live weight and perpetual low productivity of the animals. The severe nutritional limitations are further associated with delayed age at first parturition, increased interval between parturitions, increased nonproductive life of the animals, and herd wastage.

To overcome these circumstances, several alternative strategies have recently been pursued throughout the Asian region with the objective of making low-quality

Fig. 1. Goats being fed *Gliricidia* in Indonesia.

forages more useful for production (meat, milk, or draft). Foremost in these initiatives are a variety of chemical pretreatments (Jackson 1977; Ibrahim 1983; Sundstol 1984; Doyle and Pearce 1985); among these, urea treatment is currently the most widely used. The result has been a shift from a subsistence to a maintenance situation, which is achieved by increased intake, increased digestibility, or both (Ibrahim et al. 1984), and occasional growth (Perdok et al. 1982; Verma 1983) and milk-production (Davis 1983) responses.

The use of forage supplements has been secondary to these efforts. It is, however, an alternative strategy that perhaps has not been given adequate research and development attention. For a variety of reasons, this approach, more than any other, has enormous potential for application with ruminants, especially in situations where animals are abundant and varied. It is appropriate, therefore, to review the current understanding of the use of forage supplements and the benefits of this strategy.

There are many advantages concerning the use of these forages (Devendra 1988):

- availability in the farms,
- accessibility,
- provision of variety in the diet,
- source of dietary nitrogen, energy, minerals, and vitamins,
- laxative influence on the alimentary system,
- reduction in the requirements for purchased concentrates, and
- reduced cost of feeding.

Leucaena, for example, provides a valuable source of protein, energy, and sulphur for rumen bacteria. It is also used in fence lines and as a fuel.

Tables 5–8 demonstrate the potential value and use of forage supplements by individual ruminants. The tables are not exhaustive and, for reasons of brevity, refer mainly to the Asian region. Many aspects of these tables are worthy of mention.

First, with all ruminants, the use of various forage supplements consistently increased live weight gain or milk production. Second, in many instances, the beneficial response (meat and milk) was associated with a reduced cost of production. Third, of the forage supplements used, the leguminous forages have been particularly advantageous, among which leucaena has been popular. Fourth, and with only rare exceptions, stall-feeding or cut-and-carry systems are the most common production systems used compared with the grazing situation. The one reference to this (Wong et al. 1987) clearly shows that leucaena supplementation increases milk production and reduces the cost of feeding. Between grazing and the cut-and-carry systems, the former was much cheaper.

Fifth, with reference to large ruminants, the research on the value of forage supplements for draft is very sparse. One such study has been reported in Thailand. The effects of breed (Murrah × Swamp and Swamp) and feed supplement (with or without) on draft (work or no work) was studied over 6 months. The concentrate supplement consisted of cassava chips and dried leucaena leaf in a 3:1 ratio and was applied at 1.5 kg/head per day. The animals without supplements were fed on silage.

Over the first 4 months before the assessment of draft capacity in both breeds, supplementation, as one would expect, significantly stimulated growth rate. Concerning working ability, Thai swamp buffaloes ploughed more than the crossbred Murrah, and supplementation increased the area ploughed, but its effects and differences between breeds were not significant. Also, no differences were found in the speed of ploughing between breeds or because of supplementation. However, there was a tendency toward faster ploughing for both breeds when feed supplements were used (Konanta et al. 1986).

Practical application

A recent review on the inclusion of dietary proteinaceous supplementary forages, especially legumes ones, and their beneficial effects and practical application suggest the following optimum dietary levels (ODL) (Devendra 1988):

- ODL on dry-matter (DM) basis: 30–50%;
- ODL as percentage of live weight: 0.9–1.5%.

Deleterious principles

The use of shrubs and tree fodders by ruminants has some problems and deleterious effects on animals. Several of these feeds do, in fact, have serious limitations (Table 9). However, there are differences between species and between breeds within species concerning utilization and thresholds of tolerance. Clearly,

Table 5. Results of economic benefits of forage supplements in diets for buffaloes.

Feeding regime	Forage supplement	Location	Significant responses[a]	Result[a]	Reference
Grass	Leucaena + conc.	Philippines	Milk	Reduced cost/kg milk	Limon and Baula (1980)
Wheat straw + conc.	Lucerne + berseem	India	Milk	Reduced cost/kg SCM milk	Gupta et al. (1983)
Concentrates	Berseem bay	India	Milk	Reduced cost/kg milk	Chauhan and Chopra (1984)
Rice straw	Gliricidia or leucaena	Sri Lanka	Milk	Increased margin over costs	Perdok et al. (1984)
Wheat straw + conc.	Leucaena	India	LW gain	Reduced cost/kg LW gain	Akbar and Gupta (1985)
Concentrates	Leucaena	India	Milk	Reduced cost/kg FCM milk	Dharmaraj et al. (1985)
Oat silage + conc.	Berseem hay	India	Milk	Reduced cost/kg milk	Chauhan (1986)
Sugarcane tops	Leucaena	Thailand	LW gain	Increased LW gain	Snitwong et al. (1986)
Rice straw[b]	Gliricidia	Sri Lanka	Milk	Increased milk production and composition	van der Hock et al. (1988)

[a] LW, live weight; SCM, solids-connected milk; FCM, fat-connected milk.

[b] Urea ammonia treatment.

Table 6. Results of economic benefits of forage supplements in diets for cattle.

Feeding regime	Forage supplement	Location	Significant response[a]	Result[a]	Reference
Rice straw	Leucaena leaf meal	Philippines	LW gain	Reduced cost/kg LW gain	Sevilla et al. (1976)
Sugarcane top cubes	Leucaena	Philippines	LW gain	—	Lopez et al. (1981)
Rice straw	Leucaena	Philippines	LW gain	—	Trung et al. (1983)
Urea-treated rice straw	Leucaena	Thailand	Milk	Reduced cost/kg milk	Promma et al. (1984)
Rice straw	Leucaena	Thailand	LW gain	Reduced cost/kg LW gain	Cheva-Isarakul and Potikanond (1985)
Rice straw + dried poultry litter + conc.	Leucaena leaf meal	Philippines	LW gain, milk	Reduced cost/kg LW gain, reduced cost/kg milk	Trung et al. (1987)
Brachiaria decumebens	Leucaena	Malaysia	Milk	Reduced cost/kg milk	Wong et al. (1987)
Concentrates	Prosopis	India	Milk	Reduced cost/kg milk	Talapada and Shukla (1987)

[a] LW, live weight.

Table 7. Results of the benefits of forage supplements for goats.

Breed	Major feed	Forage supplement	Significant response[a]	Location	Reference
Native	Maize stover	Leucaena	LW gain	Philippines	Linggodjiwo (1976)
Crossbreeds	Napier grass	Leucaena	LW gain	Malaysia	Devendra (1982)
Native	Paragrass	Leucaena	LW gain	Philippines	Abayan and Boloran (1984)
Native	Browse	*Psorpis cineraria*	LW gain	India	Parthasarathy et al. (1983)
Native	Concentrate	Leucaena	LW gain	Philippines	Abilay and Arinto (1981)
Javanese-thin tailed	*Pennisetum purpureum*	Gliricidia	LW gain	Indonesia	Rangkuti et al. (1985)
Native	Concentrate	*Psorpis cineraria*	LW gain	India	Parthasarathy (1986)

[a] LW, live weight.

Table 8. Results of the benefits of forage supplements for sheep.

Breed	Major feed	Forage supplement[a]	Significant response[b]	Location	Reference
Local	*Pennisetum purpureum*	LE	LW gain	Indonesia	Semali and Mathius (1984)
Bannur	*Brachiaria mile-formia*	GL	LW gain + wool	India	Kantharayer and Chadhokar (1981)
Local	Rice straw	LE, GL	LW gain	Thailand	Vearasilp (1981)
Javanese thin-tailed	Mixed village feedstuffs	LE	LW gain	Indonesia	Chaniago et al. (1983)
Local	*P. purpureum*	CA	LW gain	Indonesia	Mathius et al. (1983)
Indigenous	Rice straw	CA, LE, GL	Increased ME intake and N retention	Malaysia	Devendra (1983)
Javanese thin-tailed	*P. purpureum*	GL	LW gain	Indonesia	Rangkuti et al. (1985)
Javanese-thin tailed	Rice straw + *P. purpureum*	LE	LW gain	Indonesia	Sitorus et al. (1985)
Crossbred fat-tailed	*P. purpureum*	LE	LW gain	Indonesia	Ifar et al. (1986)
Indigenous	Rice straw	LE	LW gain	Thailand	Meevootisom et al. (1987)

[a] CA, *Manihot esculenta*; GL, *Gliricidia maculata*; LE, *Leucaena leucocephala*.
[b] LW, live weight; ME, metabolizable energy.

Table 9. Examples of deleterious principles on shrubs and tree fodders.

Feed	Deleterious principles
Acacia	Cyanoglucosides, fluoroacetic acid, tannins (1.5%)
Banana leaves	Tannins
Cassava leaves	HCN (17.5 mg/100g)
Gliricidia	Tannins
Leucaena	Mimosine (3-hydroxy-4[1H]-pyridone)
Young leaves	2.1–6.8%
Mature leaves	0.3–3.7%
Stems	3.7%
Seeds	7.1%
Mesquite	Tannins (2.9%)
Water hyacinth	Oxalic acid (2.4% dry matter)

much more information is required to ascertain the nature and extent of the deleterious principles in individual feeds.

Tannins and other deleterious principles are common in many shrubs and tree fodders. The problem is more acute for browsing animals like goats which thrive on these feeds much more than sheep. However, goats appear to be more tolerant of tannins than sheep, but real reasons for this are not fully understood, but it has been suggested that the increased salivary function produces mucins that bind tannins and spare the protein for digestion (Hoffman 1987).

Farmers currently overcome and reduce these problems by feeding mixtures of the feeds with or without sun drying. This process not only extends the choice of feeds available but also dilutes and reduces problems of palatability and side effects. Little is known about ODLs of feeds from individual shrubs and trees (especially for those with deleterious principles), about how to reduce the incidence of deleterious effects, and about suitable mixtures in economic feeding systems for individual ruminants.

Conclusions

- Research on the management and use of shrub and tree fodders is limited, although their potential is increasingly being recognized.
- Priority must be given to the more important shrubs and trees appropriate to individual environments and of benefit to ruminants (with reference to rates of productivity, biomass structure, persistence, palatability, nutritional value, and comparative use by individual animal species).
- Increased attention must be given to include potentially important shrubs and trees into native pastures, alley farming, and agroforestry systems.
- The value of shrub and tree fodders is greatest in extensive systems in arid and semi-arid regions because of feed shortages. In the humid zones, leguminous fodders are especially valuable as protein supplements and in reducing the cost of feeding.
- With herbivores, small ruminants and camels currently make the most use of browse (tender shoots of twigs and leaves of shrubs and trees); tree fodders are used more as supplements by large ruminants.

- Much more information is required on feeding behaviour, palatability, patterns of animal use and productivity, management systems, tolerance to and the effects of deleterious dietary principles on animals.

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The use of shrubs and tree fodders by nonruminants

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Abstract *— The trend of increasing prices for animal feed has compelled researchers from developing countries to direct their research to nonconventional feeds, with particular emphasis on protein substitutes. The use of plant leaves as possible sources of protein is one among many possibilities. Studies on shrub and tree leaves, leaf vines, grasses, and algae and other water plants showed that, on a dry-weight basis, leaves may contain 20 to 30% crude protein, 12 to 18% crude fibre, and 500 to 650 ppm xanthophyll. Plant leaves are commonly processed into leaf meals for nonruminant animals. If processed properly, leaf meals are good pigmenting agents because of the presence of several different xanthophylls of the general family of carotenoids. Among the leaf meals, leucaena (*Leucaena leucocephala*) and cassava (*Manihot esculenta*) leaf meals are most popular. Other leaf meals, such as* Trema orientalis, Muros indica, Moringa oleifera, *and* Sesbania rostrata, *are potentially useful, but more studies are needed to determine their availability and usefulness. The use of leaf meals as feed is limited by their high fibre content and, in some cases, the presence of toxic factors or metabolic inhibitors. Thus, the idea of extracting protein from leaves was conceived to obtain a product high in protein, low in fibre, and without residual toxins. This leaf protein concentrate has a higher feeding value and can be included at high levels as a substitute for soybean oil meal. Interest in the production of leaf proteins has been slow, mainly for economic reasons. Other shrub and tree leaves are used in small quantities as soilage for swine. Limited quantities are fed to poultry in confinement. Recently, there has been increasing interest in the use of shrub and tree leaves in herbal medicines for poultry and livestock.*

Résumé *— La tendance à l'augmentation des prix des fourrages a forcé les chercheurs des pays en développement à orienter leurs recherches sur des fourrages non conventionnels en s'attachant plus particulièrement aux substituts de protéines. Les feuilles des plantes ne sont qu'une des nombreuses sources possibles de protéines. Les études sur les feuilles d'arbustes et d'arbres, les vignes feuillues, les graminées, les algues et d'autres plantes aquatiques ont montré que, en poids sec, les feuilles peuvent contenir de 20 à 30 % de protéines brutes, de 12 à 18 % de fibres brutes et de 500 à 650 ppm de xanthophylle. Les feuilles de plantes sont généralement transformées en farines réservées aux non-ruminants. Si leur préparation a été bien faite ces farines constituent de bons agents de pigmentation parce qu'elles contiennent plusieurs xanthophylles différentes de la famille des caroténoïdes. Les farines les plus populaires sont celles de leucaena (*Leucaena leucocephala*) et de manioc (*Manihot esculenta*). D'autres farines, comme celles de* Trema orientalis, Muros indica, Moringa oleifera *et* Sesbania rostrata, *notamment, présentent des possibilités qui ne pourront être déterminées qu'après d'autres* *études de leur disponibilité et de leur utilité. Leur haute teneur en fibres et le fait qu'elles contiennent parfois des substances toxiques ou des inhibiteurs métaboliques restreignent l'emploi de ces farines dans l'alimentation du bétail. C'est pourquoi on a pensé à extraire les protéines des feuilles pour obtenir un produit à teneur élevée en protéines, à faible teneur en fibres et sans toxines résiduelles. Ce concentré de protéines de feuilles a une plus grande valeur nutritive et peut être ajoutée à la ration en quantité élevée en remplacement de la farine de soja. L'intérêt pour la production de ce type de protéines n'a pas évolué très vite et cela est principalement attribuable à des raisons économiques. Des feuilles d'autres arbustes et arbres sont employées comme fourrage vert pour les porcs. De petites quantités sont données aux volailles en claustration. Depuis peu de temps on s'intéresse de plus en plus à l'emploi des feuilles d'arbustes et d'arbres dans la phytothérapie des volailles et du bétail.*

Resumen *— La tendencia a incrementar los precios de lo alimentos para el ganado ha obligado a los investigadores de los países en desarrollo a orientar su investigación hacia los alimentos no convencionales, poniendo énfasis particularmente en sucedáneos proteínicos. Entre muchas posibilidades, una es la utilización de hojas de plantas como posibles fuentes de proteínas. Los estudios realizados en hojas de arbustos y árboles, hojas de vides, pastos y algas y otras plantas acuticas demostraron que, sobre la base de peso seco, las hojas pueden tener del 20 al 30 por ciento de contenido en proteína bruta, del 12 al 18 por ciento de fibra en bruto y de 500 a 650 ppm de xantófila. Las hojas de plantas comúnnmente se procesan para hacer harinas de hoja para animales no rumiantes. Si se procesan adecuadamente, las harinas de hoja constituyen buenos agentes de pigmentación debido a la presencia de varias xantófilas diferentes de la familia general de carotenoides. Entre las harinas de hoja, las más populares son: leucaena* (Leucaena leucocephala) *y mandioca* (Manihot esculenta)*. Otras harinas de hoja, tal como* Trema orientalis, Muros indica, Moringa oleifera, Sesbania rostrata, *etc., son potencialmente útiles pero es necesario realizar más estudios para determinar su disponibilidad y provecho. El uso de las harinas de hoja como pienso es limitado por su alto contenido en fibra y, en algunos casos, la presencia de factores tóxicos o inhibidores del metabolismo. En consecuencia, la idea de extraer proteínas de las hojas se concibió para obtener un producto de alto valor proteínico, bajo en fibra y sin toxina residual. Este concentrado proteínico de la hoja tiene un valor alimenticio más alto y se puede usar en gran medida como sucedáneo de la harina de aceite de soja. Fundamentalmente por motivos económicos, la producción de proteínas de la hoja ha tardado en cobrar interés. Se utilizan, en pequeñas cantidades, otras hojas de árboles y arbustos como forraje verde para cerdos, y en cantidades limitadas, para aves de corral en estabulación. Recientemente, ha crecido el interés por el uso de hojas de árboles y arbustos en la fabricación de medicinas naturales para las aves de corral y el ganado.*

Introduction

The high cost of protein sources for poultry and livestock is a perennial problem in many developing countries. Soybean oil meal (SBOM) and fish meal are still the major sources of protein in finished feeds. The increasing importation of these protein sources contributes to the financial drain in developing countries. Also, the rising cost of these feedstuffs is fast becoming prohibitive for feed millers and growers. This has lead researchers to direct increased attention to nonconventional feeds, giving more emphasis to protein substitutes.

The use of plant leaves as a source of protein is one possible alternative. Studies on shrub and tree leaves, leaf vines, grasses, and algae and other water plants have shown that, on a 90% dry-matter basis, their crude protein (CP) contents vary from 20 to 30%, crude fibre (CF) from 12 to 18%, and xanthophyll from 500 to

650 ppm. Although plant leaves are good sources of protein, their use by nonruminants is limited by the high fibre content and, in some cases, the presence of toxic factors or metabolic inhibitors.

Leaf meals

Plant leaves are commonly processed into leaf meals for nonruminants, particularly for poultry. A good-quality leaf meal must be free of stems, kiln dried, and dehydrated. It must not be sun dried because this treatment inactivates a high percentage of the carotenoids. None of these criteria are observed in countries with poor resources, where there is lack of drying facilities at the farmer's level and where cost of energy for kiln drying is prohibitive. Thus, commercially sold leaf meals have varying amounts of stems and are sun-cured, with variable protein, fibre, and xanthophyll contents.

Leaf meals are included in poultry feeds primarily as pigmenting agents because of their low energy value (<6.25 MJ/kg) and low protein digestibility. The maximum level in broiler diets is about 3%, as high levels may decrease growth rates. Conversely, good-quality leaf meal is almost always used in feed formulations for layers, the usual upper limit being 5% by weight of feed.

In general, leaf meals are good pigmenting agents. This is due to the presence of several different xanthophylls of the general family of carotenoids. Xanthophylls are the hydroxy derivatives of carotene hydrocarbons; the hydroxyl (OH) group increases the solubility and metabolic absorption in the avian digestive system. Beta-carotene, per se, is not considered a pigment; however, after metabolic hydrolysis it becomes xeaxanthine, which is a pigment. The actual requirements for yellow-orange pigmentation of poultry meat or eggs are artificial standards governed by consumer preference, and consumer preference varies with location and ethnic origin.

Leucaena leucocephala

The most popular among the leaf meals is that of *Leucaena leucocephala* (Lam) de Wit. Known as ipil-ipil in the Philippines, leucaena is a leguminous shrub that grows very rapidly. It is resistant to drought, deep rooted, productive during the dry season, and tolerant to a wide range of soil pHs. With an average of 4.6 cuttings/year, rows 52.2 cm apart, and a seeding rate of 40.65 kg/ha, the annual green weight yield of leucaena is about 72 t/ha (Kinch and Ripperton 1962). The annual dry weight yield is 20 t/ha (green:dry = 3.6:1, at 10% moisture). In its fresh form, leucaena is a roughage feed for ruminants and, as leaf meal, it is commonly used in poultry and swine feeds.

Leucaena contains mimosine, a toxic nonprotein amino acid (Table 1). The highest mimosine concentrations are found in the leaves (5.3%), lower amounts are found in mature leaves, pods, and roots (1.36%), and none is found in the stems. Native leucaena leaves contain more mimosine (3.5%) than Hawaiian leucaena leaves (2.0%) (Carangal and Catindig 1955). Mimosine toxicity may be attributed either to its phenolic or alkaloidal properties or its inhibiting action on the metabolism of two aromatic amino acids: phenylalanine and tyrosine. Its effects

Table 1. The chemical and nutrient composition of *L. leucocephala* and *M. esculenta* leaf meals.

Component	*L. leucocephala*		*M. esculenta*	
Moisture (%)	11.5		12.0	
Crude protein (%)	22.8		23.0	
Crude fibre (%)	12.7		11.7	
Ether extract (%)	6.8		7.9	
Ash (%)	7.2		6.4	
Calcium (%)	2.17		1.56	
Phosphorus (%)	0.15		0.23	
Xanthophyll (ppm)	600.0		566.0	
Mimosine (ppm)	3.0		—	
Prussic acid (ppm)	—		10.0	
AME (kJ/kg)	—		3 783	
TME (kJ/kg)	1 092		6 079	
	TAA (mg/g)	TAAA (%)	TAA (mg/g)	TAAA (%)
Phenylalanine	10.60	35.41	17.52	76.01
Valine	10.90	27.83	18.01	78.12
Threonine	9.29	22.98	15.46	73.40
Methionine	1.68	9.17	3.40	73.96
Arginine	12.54	36.46	18.42	78.58
Histidine	4.42	19.59	6.49	88.65
Isoleucine	8.70	29.82	14.34	77.11
Leucine	16.07	23.68	27.91	27.03
Lysine	12.10	23.35	17.51	65.63

Source: Lopez (1986).

Note: TAA (total amino acids), TAAA (total available amino acids), AME (apparent metabolizable energy), and TME (true metabolizable energy) were determined using 2-year-old cockerels and the method of Sibbald (1976).

may also be associated either with its complex formation with pyridoxal phosphate, thus inhibiting the activity of pyridoxal-requiring transaminases, or its chelation with metal ions, thus inhibiting the activity of metal-containing enzymes.

Several studies have examined methods of detoxifying leucaena leaf meal (LLM). After observing a decrease in urinary mimosine and a simultaneous increase in fecal mimosine, Yoshida (1944) suggested adding iron salt to the LLM-containing ration. Matsumoto et al. (1951) reported that ferrous sulfate ($FeSO_4$) supplementation or high temperature treatment in the presence of moisture was effective in reducing mimosine. Likewise, Linggodjiwo (1976) claimed that heating the green leaves and immature pods in a moist environment at 70–100°C for 72 h will destroy 40–60% of the mimosine. The most recent work was done by Mendoza and del Rosario (1988). They examined four methods: sun drying fresh leaves; oven drying fresh leaves at 45°C; placing leaves in a plastic bag and immersing it in water at 70°C for 10 min followed by oven drying at 45°C for 24 h; and soaking leaves in water at 70°C for 10 min followed by oven drying at 45°C for 16 h. All four treatments resulted in a 65–85% reduction of mimosine in leucaena. Mendoza and del Rosario (1988) also reported that alkali treatment using 0.1–0.5 *N* NaOH reduces or eliminates mimosine (46–100%). Although heat treatment by extrusion lowered the mimosine level, microwave cooking did not appreciably reduce mimosine. However, mild heat and microwave treatments together produced the least change in the mono- and di-hydroxypyridine and total xanthophyll levels. Alkali and extrusion treatments reduced the pigments 10–50 times more than the other treatments.

Springhall and Ross (1965) reported that LLM supplemented with $FeSO_4$ during the growing stage of laying hens did not significantly alter egg production, egg weight, or feed-conversion efficiency. Although it took longer for the birds to reach sexual maturity, they had lighter body weights after 8 months of production. Similarly, when LLM supplemented with $FeSO_4$ was given to birds during the laying stage, no significant differences were found in egg production, feed conversion efficiency, or fertility; however the hens were lighter in weight and produced smaller eggs compared with the control hens.

Labadan et al. (1969) observed a linear depression in the growth of chicks when fed 0, 10, 20, 30, and 40% LLM in their diets. Mortality was also high for the chicks fed a diet containing 40% LLM. Significant reductions in average comb and testes weights of cockerels were also observed. Scott et al. (1969), claimed that leucaena inhibited the maturation of ovaries when included at the 30% level in isocaloric diets. This was supported by Alejar (1974), who observed zero egg production at 26 weeks of age in young pullets fed 30% LLM (equivalent to 1.2% mimosine in the diet). Both studies observed the development of comb and ovaries to be adversely affected. Directo et al. (1971) observed significant histopathological changes in the liver, kidney, and testes of cockerels given high levels of LLM. The most evident clinical responses they observed were low feed consumption, stunted growth, emaciation, and high mortality rate. Lopez et al. (1978) indicated that egg production was significantly decreased in birds fed 10% LLM. However, with $FeSO_4$ supplementation at 0.2 and 0.4% of the diet, egg production was comparable to treatment groups receiving no LLM (control) and 5% LLM. Furthermore, egg production at 5% LLM with or without $FeSO_4$ supplementation was comparable to the control diet (Table 2).

Feeding trials with growing pigs have shown that feeding LLM at 5, 10, and 15% caused no ill effects (Patricio 1956; Iwanaga et al. 1957; Rivas et al. 1978). In fact, LLM at 5 and 10% levels is useful in growing and fattening swine. Rivas et al. (1978) found that pigs fed 20% leucaena without $FeSO_4$ showed the lowest growth rate, average feed intake, and feed conversion efficiency; the pigs also lost hair and had defective hoofs and pasterns. Growing finishing pigs, however, could be raised using a diet containing 20% LLM, provided 0.4% $FeSO_4$ was added. Moreover,

Table 2. Average total egg production per bird during the first 5 months (140 days) of laying from molting.

LLM (%)[a]	0.0% $FeSO_4$	0.2% $FeSO_4$	0.4% $FeSO_4$	Mean
0	105de	105de	106de	105c
5	107de	109de	103de	106c
10	92bc	102de	105de	100b
20	73a	83ab	96cd	84a
Mean	94a	100b	102b	

Note: Values followed by the same letter(s) are not significantly different at the 5% level of probability (Duncan's multiple-range test).

[a] LLM, leucaena leaf meal.

pigs weighing 50 kg or more could use higher levels of LLM better than younger or smaller pigs.

Early findings indicated that sows fed fresh leucaena failed to conceive after breeding for three or four cycles (Willet et al. 1945). This was confirmed by Wayman and Iwanaga (1957), who showed that with 15% LLM, the gilts had lower conception rates and smaller litter sizes and weights.

All these studies and the recommendation of Le Anh (1962) suggest that LLM should be limited to 5% in chick and 10% in pig diets.

Extruded LLM

Talamo (1987) evaluated the feeding value of LLM after it passed extrusion to determine if mimosine was destroyed or reduced. Talamo claimed that extruded LLM had more ether extract (EE) and nitrogen-free extract (NFE) and less CP and CF compared with nonextruded LLM. Birds fed 10% extruded LLM showed significantly higher body weight gain, feed consumption, feed conversion efficiency, and dressing percentage than those fed at the 20% level. Apparently, extrusion of LLM does not markedly improve its feeding value. Yellow pigmentation in the carcass increased with increasing levels of LLM.

Manihot esculenta

Lopez (1986) studied the chemical and nutritive value of cassava (*Manihot esculenta* Crantz) leaf meal (CLM) (Table 1). The potential yield of cassava leaves ranges from 10 to 32 t/ha. The major deterrent to the extensive consumption of cassava leaves by livestock is its content of prussic acid or hydrocyanic acid (HCN) (about 380 ppm). However, HCN is completely destroyed when the fresh leaves are processed into leaf meal. Nutritionally, the quality of CLM is higher than that of LLM, in spite of its deficiency in methionine and low digestibility (Eggum 1970; Lopez 1986).

Ross and Enriquez (1969) included graded levels of CLM in chicken and quail diets and noted a linear depression in growth. Khajarern and Khajarern (1986) reviewed the various studies on CLM and fresh cassava leaves fed to poultry and hogs. They claimed that, in both poultry and pigs, 20% CLM depresses live weight gain and feed conversion efficiency; the addition of sodium thiosulfate, methionine, molasses, or vegetable oil partially corrected this depression. They suggested that 5% CLM in broiler diets and 17% CLM in diets for replacement pullets, with proper supplementation, is appropriate. Vibulchai (1984) showed that young finishing pigs performed well on cassava silage diets containing 7% CLM (dry-weight basis).

Lopez (1988) incorporated CLM in six cassava-based broiler diets such that the cassava meal contained xanthophyll equivalent to that in yellow corn. The 7-week feeding trial showed that pigmentation of the skin, fat, breast, and shanks of broilers given cassava meal fortified with CLM was markedly less than with the yellow corn diet.

Trema orientalis

Castillo et al. (1981) used anabiong (*Trema orientalis* [Linn.]) leaf meal at 5, 10, 15 and 20% in the finisher diets of 5-week-old broilers and found no significant depression in growth. Supplementation with $FeSO_4$ at the 15 and 20% levels did not improve performance compared with broilers fed the same levels of LLM with $FeSO_4$ supplementation. Mashed and pelleted diets containing 20% anabiong leaf meal produced the same results in broilers. The body weights of broilers in all dietary treatments were, however, unsatisfactory (967–1 028 g).

In another experiment, Castillo et al. (1981) reported that the egg production of SCWL (single-comb white leghorn) layers decreased with increasing levels of leaf meal in the diet; however, the differences were not statistically significant. They also reported that 3–5% levels of good-quality anabiong leaf meal added to white corn, cassava, sweet potato, or sorghum diets produced egg yolks with a desirable yellow pigment, comparable to egg yolks of layers fed 40% yellow corn.

Sesbania rostrata

Sazon (1988) studied the chemical composition and feeding value in layer diets of *Sesbania rostrata* leaf meal (SLM). On a dry-weight basis, SLM has 29.7% CP, 7.6% EE, 15.3% CF, 27.6% NFE, 7.8% ash, 0.78% Ca, 0.23% P, and 467 ppm xanthophyll. Laying mashes were formulated to contain graded levels (0, 2.5, 5.0, 7.5, and 10%) of SLM. The 9-week study showed that the feed consumption of pullets decreased when the diet contained more than 5% SLM. Similarly, percent egg production and feed efficiency decreased with increasing levels of SLM in the diet. Body weight, egg weight, and egg quality were not significantly affected, even at 10% SLM. Yolk colour intensified as the leaf meal level increased.

Moringa oleifera

Leaves from malunggay (*Moringa oleifera*), a legume tree, have about the same CP and P levels as *Leucaena leucocephala* leaves (Cariaso 1988). When the leaf meal is fed to 1-week-old broilers up to a level of 5%, growth rate, body weight gain, feed consumption, and feed efficiency are not adversely affected. However, higher levels of leaf meal (7.5 and 10%) resulted in depressed growth rate, body weight gain, and feed efficiency, and increased feed consumption by the broilers.

Muros indica

Castillo et al. (1980), using 2–10% mulberry (*Muros indica*) leaf meal in broiler feed, reported that body weight gain and feed conversion efficiency decreased with increasing levels of the leaf meal. Furthermore, they reported that although 0.5% $FeSO_4$ improved the performance of broilers fed 9% LLM, broilers fed mulberry leaf meal with $FeSO_4$ supplementation did not show any improvement.

Pisonia alba

Rigon et al. (1983) prepared colis (*Pisonia alba*) leaf meal containing 18.5% CP, 15.8% CF, and 2.6% EE and added it to commercial broiler mash at 5, 7.5, and 10%. Performance of broilers decreased with increasing leaf meal levels.

Leaf protein xanthophyll concentrate

The idea of extracting protein from leaves surfaced at the beginning of the 20th century (Fig. 1). The purpose was to increase the feed's protein content to the level found in soybean oil meal (SBOM), decrease its fibre, and remove possible toxic factors. Leaf protein concentrate (LPC) has a higher feeding value and can, therefore, be used at a higher inclusion rate as a substitute for soybean oil meal and as a concentrate source of xanthophyll, compared with leaf meals. Despite the recent rising interest in the production of leaf protein, production on a commercial scale has been slow, primarily because of technological and economic factors. The yield of LPC is low, the quality of the product is variable, and the cost of

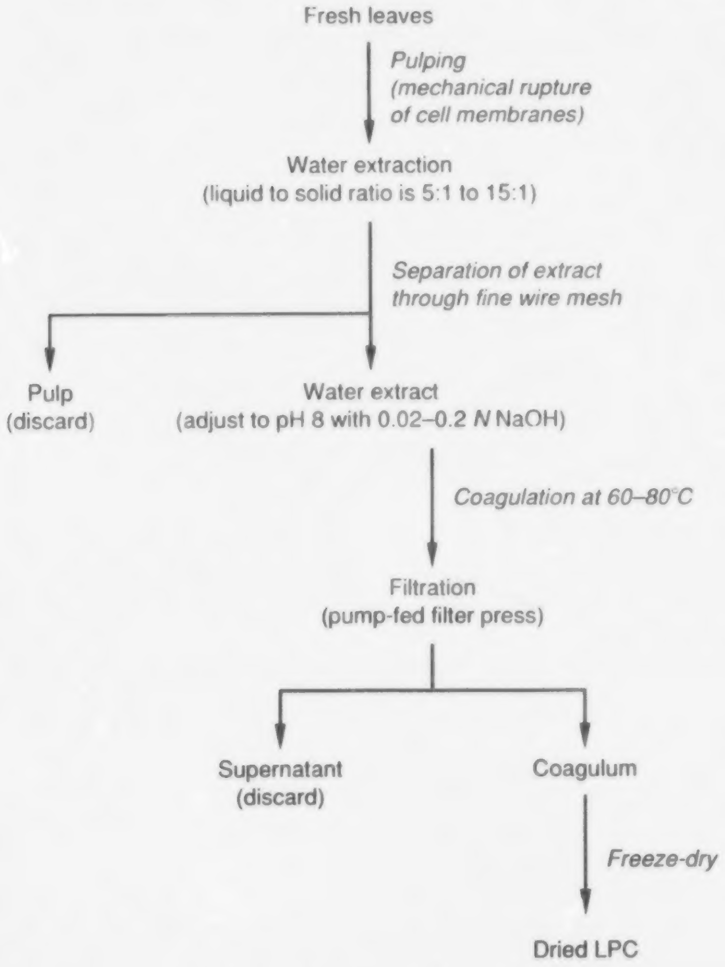
Fresh leaves
Pulping
(mechanical rupture
of cell membranes)
Water extraction
(liquid to solid ratio is 5:1 to 15:1)
Separation of extract
through fine wire mesh
Pulp
(discard)
Water extract
(adjust to pH 8 with 0.02–0.2 N NaOH)
Coagulation at 60–80°C
Filtration
(pump-fed filter press)
Supernatant
(discard)
Coagulum
Freeze-dry
Dried LPC

Fig. 1. Leaf protein concentrate (LPC) production.

production is still far from being competitive with the price of traditional protein sources such as SBOM.

Cowlishaw et al. (1956) recovered 30–40% of leaf protein. Chayen et al. (1961) observed that, at the leaf stage, the yield and percent protein of the concentrate is optimum. When plants become stalky, as with flowering grasses, both yield and percent protein decrease. When the leaf begins to yellow and become fibrous, only 15–20% of its protein will be extractable, even if water and alkali are added.

Pirie (1971a) reported that, from 1 t of raw green matter with 20–22% dry matter, 90–100 kg concentrate and 100–110 kg by-products can be obtained. He reported that half of the leaf protein appears in the first extract and the rest is recovered in the second extract. Lopez (1979) showed that the percentage recovery of LPC from seven plant species varied from 4.4% for banana (*Musa sapientum*) to 23.6% for mixed weeds (*Mikania cordata*), based on the leaf material being 90% dry matter. The low yield of LPC, particularly with banana and acacia (*Samania saman*), is related more to the physical characteristics than to the protein content of the fresh leaf materials. Banana and acacia leaves are more fibrous, dry, and tough compared with other species used. When recovery is expressed in terms of CP of both the raw materials and final products, it varies from 5.5% (acacia) to 37.4% (leucaena). At this rate of recovery, the method of extraction is not satisfactory and needs to be improved to make LPC production more viable.

Legumes are the best sources of easily extractable and good-quality protein (Bryers 1961; Lopez 1986). Good results were also obtained with a few of the more common weeds, which yielded more CP than leaves from vegetable crops. It is impractical to use vegetable crops for this purpose, other plants, especially those posing as weeds or those that are a nuisance to crops as well as animals and humans, should be exploited.

Lopez (1979) studied the chemical composition and feeding value of LPC from seven plant species. On a 90% dry-matter basis, CP varied from 28.6% for acacia LPC to 41.6% for leucaena LPC, with an average of 34.5%. There were wider ranges in CF (9.8–26.6%) and ash (5.8–19.6%). Similarly, Ca content varied from 0.86–3.55% and P content from 0.16–0.43%. The xanthophyll concentration determined from fresh leaves of water hyacinth (*Eichornia crassipes*) ranged from 584 to 667 ppm; however, only 91 to 103 ppm was found in LPC. This suggests that about 85% of total xanthophyll was lost during processing. Results from chemical analyses of these LPC samples suggest that their quality was inferior compared with Pirie's (1971b) suggestion that an acceptable LPC should contain 40–44% CP, 40–45% NFE, 2–4% fat, 1–5% CF, and 12–20% ash. All seven LPCs were higher in CF and lower in CP. The low CP of the product may be due to poor cell rupture and oversoaking of the ground leaves; the high CF may be due to poor separation of the juice from the pulp, which was done manually.

Data on total feed consumption of broilers showed that the acceptability of the different LPCs differed significantly (Lopez and Mania 1982). Cassava, banana, mixed-weeds, and acacia LPCs were preferred by broilers over water hyacinth, leucaena, and gliricidia (*Gliricidia sepium*) LPCs (Table 3). Except for cassava, all LPC-fed birds had lower feed consumption than the control (SBOM) diet ($P < 0.05$). Because LPC varies in CP, depending on the source, the amount added to diets will correspondingly be different. Apparently, acceptability of the LPC in terms of feed consumption is unrelated to CP level or the actual level of each LPC

Table 3. Average total feed consumption and body weights of broilers fed different leaf protein concentrates.

Protein source[a]	Avg. total feed consumption (g) (2–5 weeks)	Avg. body weight (g) (5 weeks)
SBOM (control)	1 422a	726a
Acacia LPC	1 269bc	551c
Banana LPC	1 311bc	563c
Cassava LPC	1 328ab	534c
Leucaena LPC	1 147d	547c
Gliricidia LPC	1 211cd	573c
Mixed-weeds LPC	1 305bc	554c
Water hyacinth LPC	1 139d	623b

Note: Values followed by the same letter(s) are not significantly different at a 5% level of probability (Duncan's multiple-range test).

[a] Leaf protein concentrates (LPCs) 50% of the CP from soybean oil meal (SBOM); on a CP basis, 1 kg SBOM = 1.58 kg acacia LPC = 1.47 kg banana LPC = 1.19 kg cassava LPC = 1.12 kg leucaena LPC = 1.34 kg gliricidia LPC = 1.44 kg mixed-weeds LPC = 1.50 kg water hyacinth LPC.

in the diet. Similarly, a high CF content, such as in banana LPC, is unrelated to feed consumption.

Despite differences in feed consumption, broiler body weights at 5 weeks of age were not statistically significant, except for water hyacinth LPC (Table 3). Because all experimental diets were isocaloric and isonitrogenous, the poor performance of the birds may be related to the LPC source, which may be associated with toxic factors or metabolic inhibitors. Birds fed cassava LPC showed the lowest body weight. This was probably due to the presence of prussic acid in fresh cassava leaves. Similarly, fresh leucaena leaves contain a toxic amino acid, mimosine, and acacia leaves may contain a toxic alkaloid.

It is possible that combining LPC with SBOM may result in a better amino acid combination in the resultant diet. Water hyacinth LPC, for example, is better in combination with SBOM than the other LPCs. Sentheshanmuganathan and Durand (1969) found that *Gliricidia sepium* LPC contains 0.92% methionine, 2.48% lysine, and 0.72% tryptophan, comparable to the amounts of the same amino acids in SBOM. Cassava LPC contains too little available methionine and is marginal in tryptophan (Eggum 1970). The process of preparing leaf protein concentrates can destroy some essential amino acids or result in poor availability.

Birds on LPC diets had deep yellow skin, fat, breast, and shanks. The degree of pigmentation varied among LPCs: *M. esculenta* > *L. leucocephala* > *M. cordata* > *M. sapietum* > *G. sepium* > *S. saman*.

In another experiment (Lopez 1979), water hyacinth was studied more intensively in broilers using three feeding systems: "straight feeding" for 8 weeks of LPC-mixed diet; feeding of LPC-mixed diet from weeks 1 through 4 followed by the control diet (zero LPC) from weeks 5 through 8; and feeding of LPC-mixed diet from weeks 5 through 8 following 4 weeks of the control diet. The control diet consisted of a basal diet containing 20% SBOM, and the four treatment groups consisted of 7.5, 15.0, 22.5, and 30.0% water hyacinth LPC in the mixed diets equivalent to 25, 50, 75, and 100% substitution of CP in SBOM in the control diet. The study showed that feed consumption generally decreased as the level of water hyacinth LPC increased (Table 4). The adverse effect was most noted for birds on straight feeding (LPC-mixed diet only). Although the decreasing trend on feed consumption was also observed in the other two systems, the effect was much less during the starter period, followed by the control diet in the finishing period.

Likewise, the average body weight of birds decreased as substitution of SBOM with water hyacinth LPC increased (Table 4). In the two feeding systems that involved alternate feeding of the control and water hyacinth LPC diets during the starting and finishing periods, body weight did not differ significantly ($P > 0.05$) at all levels of SBOM substitution. In the straight feeding system, however, the body weight of birds at the 50% level of substitution or higher was significantly lower ($P < 0.05$) than birds on alternate feeding.

The decreased body weight of broilers fed higher levels of water hyacinth LPC may be due to lower feed consumption and poor protein availability. Kohler and Bickoff (1971) explained that overheating the LPC from 80°C to as high as 100°C, in the process of either cooking or drying, may reduce the biological value and total digestibility by 5–6% and 10–20%, respectively. In this study, reduction in feeding value was higher than 20% when all the SBOM was substituted with water hyacinth LPC or when the LPC was fed during the finishing period or by straight feeding.

Feed conversion efficiency was highest for birds on the control diet. Substitution of SBOM with LPC decreased feed conversion efficiency. However, among water hyacinth LPC diets, there was no significant difference ($P > 0.05$) in feed conversion efficiency. Duckworth et al. (1961) reported that diets containing 10% dried LPC hindered growth but improved feed conversion efficiency. Hollo and Koch (1971) suspected that when green plant concentrate was added to the diet in

Table 4. Average total feed consumption and body weights of broilers fed different levels of water hyacinth LPC after 8 weeks.

Water hyacinth LPC (%)	System 1[a]	System 2[a]	System 3[a]
	Total feed consumption (g)		
0.0	3315a	3315a	3315a
7.5	3033bc	3296a	3072bc
15.0	2868de	3093b	2842e
22.5	3007c	3083b	2829e
30.0	2832e	2936d	2502f
	Body weight (g)		
0.0	1454a	1454a	1454a
7.5	1362abc	1427ab	1381ab
15.0	1262de	1210efg	1126fg
22.5	1273cde	1335bcd	1196efg
30.0	1123g	1219efg	916h

Note: Values followed by the same letter(s) are not significantly different at a 5% level of probability (Duncan's multiple-range test).

[a] System 1, control diet from weeks 1 through 4, LPC-mixed diet from weeks 5 through 8. System 2, LPC-mixed diet from weeks 1 through 4, control diet from weeks 5 through 8. System 3, 8 weeks of LPC-mixed diet.

high levels, certain accompanying substances may adversely influence feed efficiency.

Duckworth et al. (1961) reported that adding 7% dried LPC to a diet of barley–millet offal resulted in the same rate of growth and feed conversion efficiency as the standard diet in hogs. However, a hog starter diet containing 7 or 8% white fish meal and 10% dried LPC hindered growth but improved feed conversion efficiency. For a starter diet, 4–5% dried LPC had a beneficial effect when the rest of the hog's supplementary protein was derived from ground seed meal.

Alcantara (1980) fed water hyacinth protein extract (WHPE) to growing pigs and reported decreasing growth performance and feed efficiency with increasing substitution of CP in the SBOM. Alcantara reported that a 25% substitution rate did not significantly affect the performance of growing pigs; however, at 50 and 75% levels, there was a significant drop in performance and in nutrient digestibility.

Fresh green leaves (soilage)

Leucaena leaves are not only extensively used as a leaf meal but are also gaining popularity as a green feed among local poultry and swine raisers. Dingayan and Fronda (1950) reported that, of the three kinds of fresh green leaves fed to chicks (leucaena, centrosema [*Centrosema pubescens* Benth.], and sweet potato [*Ipomea batatas* Linn.]), leucaena resulted in the heaviest chicks and the lowest mortality.

Apart from leucaena, tree legumes like *G. sepium*, *Calliandra calothyrsus*, and *Albizia lebeckoides* are widely planted in Indonesia to prevent erosion, enrich the soil, and provide wood for fuel and feed for animals. Mahyuddin (1983) assessed the nutritive value of these plants, which are high in nitrogen (3.5–4.5% N). Gliricidia was more acceptable to livestock than either *A. lebeckoides* or *C. calothyrsus* because of its low tannin content. These trees are promising as sources of leaf meal.

Winged bean (*Psophocarpus tetragonolobus*) is a legume grown almost exclusively in Papua New Guinea and Southeast Asia. Its leaves have one of the highest protein contents among tropical forage legumes (38% based on 90% dry matter) and have a great potential for use in poultry feed.

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Toxic factors and problems: methods of alleviating them in animals

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Abstract *— The problem of overt toxicity in potential forage plants is one end of a continuum of effects that include aversion responses, reduced intake or digestibility, and induced deficiencies. All these effects are caused by secondary constituents — compounds not involved in essential metabolism and found only in particular plant species. Secondary compounds affect the use of tropical trees and shrubs as feed more strongly than most other forages. In particular, phenolic compounds may occur at very high levels. Most secondary compounds appear to have adaptive value to the plant in controlling predation by vertebrate or invertebrate herbivores, bacteria, and fungi. They should thus be considered an inescapable component of the fitness of the plant for its particular environment. Therefore, rather than attempting to reduce the level of such compounds (which may reduce the productivity of the plant), it is better to develop methods for overcoming their antinutritional effects on livestock. The first step is to identify the nature and distribution of any adverse factors. Possible means of overcoming them include: "dilution" by using mixtures of species; treatment, such as wilting; supplements, such as sulphate or polyethylene glycol; or the introduction of new or adapted rumen microorganisms. In general, the foregut fermentation of the ruminant provides a powerful method for detoxifying forages.*

Résumé *— La toxicité patente des plantes susceptibles d'être employées comme fourrage se trouve à l'extrémité du spectre qui comprend les réactions d'aversion, l'absorption réduite d'aliments ou la digestibilité et les déficiences induites. Tous ces effets sont attribuables à des éléments secondaires — des composés qui n'entrent pas dans le métabolisme essentiel et qui ne sont trouvés que dans certaines espèces de plantes. Ce sont ces éléments secondaires qui influent sur l'emploi d'arbres et d'arbustes tropicaux comme fourrage plus que pour presque tout autre type de fourrage. En particulier, les composés phénoliques peuvent atteindre des niveaux élevés. La majorité des éléments secondaires semblent être liés à la capacité d'adaptation de la plante en lui permettant de lutter contre les prédateurs vertébrés ou invertébrés herbivores, les bactéries et les champignons. Il faut donc les considérer comme des éléments essentiels à la santé de la plante dans son milieu particulier. Donc, au lieu d'essayer de réduire la quantité de ces éléments (ce qui pourrait réduire la productivité de la plante), il vaudrait mieux trouver des méthodes pour contrer leurs effets antinutritifs sur le bétail. Dans un premier temps, il faut déterminer la nature et la distribution de tout élément nocif. Quant aux moyens possibles de les contrer ils comprennent la «dilution» en mélangeant les espèces; des traitements comme le flétrissement; le recours à des additifs comme le sulfate ou le glycol de polyéthylène ou l'introduction de nouveaux microorganismes* *dans la panse des ruminants ou de microorganismes adaptés. En général, la fermentation dans la panse offre aux ruminants une excellente façon de détoxification des fourrages.*

Resumen *— La toxicidad evidente de las plantas forrajeras es uno de los problemas presentes entre una serie de efectos que comprenden respuestas de aversión, bajo consumo o digestibilidad reducida y provocación de trastornos. Todos estos efectos son causados por elementos secundarios (compuestos no involucrados en el metabolismo esencial y que se encuentran solamente en especies de plantas determinadas). Los compuestos secundarios afectan a los árboles y arbustos tropicales mucho más que a la mayoría de otros forrajes. En especial, los compuestos fenólicos pueden aparecer en niveles muy altos. La mayoría de los compuestos secundarios parece adaptarse a la planta para controlar la depredación causada por herbívoros vertebrados e invertebrados, bacterias y hongos. En consecuencia, se los debe considerar como un componente ineludible para la adaptabilidad de la planta a su medio específico. Por lo tanto, antes que tratar de reducir el nivel de dichos compuestos (lo que podría reducir la productividad de la planta) es mejor desarrollar métodos para eliminar sus efectos antinutritivos en la ganadería. El primer paso consiste en determinar la naturaleza y distribución de los factores adversos. Las formas posibles de eliminarlos comprenden: "dilución" usando mezclas de especies; tratamiento, tal como marchitez; aditivos, tal como sulfato de glicol o polietileno de glicol, o la introducción en el rumen de microorganismos nuevos o adaptados. En general, la fermentación en la parte anterior del tubo digestivo de los rumiantes es un poderoso método para desintoxicar forrajes.*

Plant toxins in their natural context

Toxic forages cause losses of livestock. However, the production implications are much wider than visible livestock losses. They are indicated better by considering, in a typical tropical forest association, how few of the woody plants are heavily used by mammalian herbivores or, in mixed-farming systems in the humid tropics with cut-and-carry systems of feeding, how many accessible woody plants appear to be largely unused by farmers. It is a cliché that low productivity of village livestock is due to poor-quality feed. The protein and fibre levels of such feeds sometimes show that the feed is of good quality (Lowry, Thahar et al. 1983).

Overt toxicity of a plant is one end of a continuum of effects. There may be simple aversion: the animal shows considerable reluctance to eat the plant but, when induced to do so, the plant proves to be nontoxic and of high quality. More frequently, the animal will not reject a plant entirely, but voluntary intake will be low as may also be digestibility and animal performance. Sometimes there may be a positive response to minerals (e.g., calcium and sulphur) even if they are not deficient, indicating that there may be an induced deficiency caused by something in the plant. There may also be an acute toxin associated with such complete aversion that the plant rarely causes intoxication; there is no "toxic problem," but the plant may be an unused resource and often a prolific weed, as with *Cryptostegia grandiflora* (rubber vine) in tropical Australia (Everist 1974).

All these effects are due to a diverse range of plant constituents called "secondary compounds." These secondary compounds play no role in the internal (primary) metabolism of the plant and vary widely in chemical structure and in level and frequency of occurrence; however, there is a tendency for related compounds to be found in related taxa. It is now widely accepted that secondary compounds mediate interactions between the plant and other organisms in the environment (Rosenthal and Janzen 1979), a view that was first comprehensively developed for forage plants by Culvenor (1970). In many cases, this amounts to a protective role against vertebrate and invertebrate herbivores or microbial pathogens. Such compounds are also called allelochemicals. Livestock losses result in the rather rare case where the effect of the secondary compound has been insufficient to prevent a substantial intake of the plant. The greatest diversity and intensity of predation on plants comes from insects, not mammals; one would expect chemical defences to be organized accordingly. In some cases, the adverse effects on livestock of a plant constituent may be incidental to its main role in reducing insect attack. Such cases should be easier to deal with than those where a compound has evolved as a defence specifically against browsing. Even such a well-known mammalian toxin as mimosine probably has an anti-insect role in nature.

The particular significance of secondary compounds for the wider development of woody forage plants is that they are much more of a problem than in temperate pasture plants on which much of animal production research is based. There are three reasons for this.

First, tropical plants are in contact with a greater diversity of more continuously active herbivores and pathogens than are temperate plants. To survive in such an environment, a correspondingly higher level and variety of protective compounds would be expected. There are many individual results that support this view, but the only systematic survey is that of Levin and York (1978), showing a higher incidence in tropical plants of the most bioactive group of compounds, the alkaloids.

Second, leaves of woody plants tend to have more secondary phenolics, particularly tannins, than do herbaceous plants, even in the same plant family. Although this generalization has been expressed for some time (Bate-Smith 1962), there is still not wide awareness of it as an aspect of feed plant composition.

Third, for plants growing under strong environmental limitations, a loss of tissue to herbivores is more serious than for plants in an optimum environment. Such plants are more likely to be protected by high levels of allelochemicals (Coley et al. 1985). This is relevant because the most obvious environmental constraint is low soil nutrient status and because many species under consideration as tree forages are envisaged for use on low-fertility sites unsuitable for cropping. In the case of *Lotus pedunculatus*, condensed tannin (CT) levels are markedly elevated (from 5 to 12% dry weight) when the plant is subject to nutrient stress (Barry and Blaney 1987). However, one should be wary of this as a generalization as we have found that the high CT level in *Calliandra callothyrsus* is certainly not affected by soil nutrient status (B. Palmer and J.B. Lowry, unpublished). Thus, it appears that the response of secondary compound level to soil fertility is a characteristic of the species.

Chemical nature of plant toxins

There are many compounds that are known to cause intoxication of livestock, but surprisingly few publications refer to woody forages. This reflects the distribution of research effort rather than that of the compounds. Some are also characteristic of genera in which the herb/shrub distinction is rather arbitrary (e.g., indospicine in *Indigofera* spp. and pyrrolizidine alkaloids in *Crotalaria* spp.). Recent overviews of forage plant toxins include Keeler et al. (1978), Cheeke and Hull (1985), and Seawright et al. (1985). This paper comments on some toxins known to have caused problems specifically with woody forages.

Nonprotein amino acids

Nitrogen-fixing trees may have nitrogen surplus to the requirements of primary amino acid metabolism. This nitrogen may be diverted into the production of alkaloids or distinctive and unusual amino acids that accumulate as secondary metabolites. Often, these amino acids are structurally similar to essential amino acids: when absorbed by the animal they disrupt or interfere with some step in amino acid metabolism and are thus toxic.

Mimosine is a nonprotein amino acid found in a few species of *Mimosa* and all species of the closely allied genus *Leucaena*. It has had considerable prominence because of the importance of *L. leucocephala* (Anon. 1984). Mimosine has acute (cytotoxic) effects on higher animals and is readily converted to 3-hydroxy-4(1H)pyridone, which has chronic (goitrogenic) effects in mammals.

Fluoroacetic acid is a secondary compound in certain species of *Acacia*, *Oxylobium*, and *Gastrolobium* (Leguminosae), but is chemically identical to the 1080 poison used in rodent control. Fluoracetate inhibits the citrate cycle and has caused heavy livestock losses in certain areas of Australia (Everist 1974) and Southern Africa (Vickery and Vickery 1973). Like mimosine, fluoracetate does not reduce palatability, but, unlike *Leucaena*, animals may develop an aversion from sublethal intakes. In Australia, certain indigenous herbivores have developed a high tolerance to fluoracetate in areas where fluoracetate-containing plants are abundant (Mead et al. 1985). The existence of such tolerance suggests the possibility of detoxifying adaptations for domestic livestock.

Toxic terpenoids and steroids

Several families of secondary compounds have in common a biosynthetic origin from the linking of branched C-5 (isoprenoid) units. The terpenoids include the carotenoids, natural rubber, the C-10 volatiles in essential oils, and the large and important family to steroids. They also include an array of C-15, C-20, and C-30 compounds with fused ring systems and a wide variety of structures. Most have little obvious biological activity, but there are many toxic compounds with rather diverse effects.

Ngaione, for example, is a sesquiterpenoid (C-15) compound found in some Australian and New Zealand species of *Myoporum* (Myoporaceae). In particular, *M. deserti* has caused heavy losses of sheep in Australia, apparently through the acute liver toxicity of ngaione and related compounds (Everist 1974). Ngaione is identical to ipomeamarone, a fungal metabolite formed on sweet potato, which is a chronic liver toxin.

Leaves of the widespread weedy shrub *Lantana camara* (Verbenaceae) contain lantadenes. These triterpenoid (C-30) compounds are hepatotoxic but with rather different activity. A distinctive early feature of lantadene toxemia is rumen stasis followed by further absorption of toxin from the rumen (McSweeney et al. 1985). Liver damage is accompanied by photosensitization, resulting from the porphyrin products from chlorophyll not being degraded and excreted in the biliary system. When carried by the blood to tissues exposed to light, the porphyrins transfer light energy to tissue-damaging reactions.

Hydrolyzable tannins

Hydrolyzable tannins are complex esters consisting of a glucose "core" surrounded by various combinations of polyphenolic acids. If the main product on hydrolysis is gallic acid, they are also known as "gallotannins." "Ellagitannins" are those where the main product is the C–C linked dimer of gallic acid, ellagic acid. Tannins occur in several different plant families, but almost entirely in woody rather than herbaceous species. Gallotannins in the young leaves of shin oak (*Quercus havardi*) have caused substantial seasonal livestock losses in North America (Pigeon et al. 1962). They may also be responsible for the economically important toxicity of *Terminalia oblongata* in Australia (Everist 1974; Payne 1975) and have been tentatively implicated in the toxicity of *Acacia salicina* (McCosker and Hunt 1966) and *Ventilago viminalis* (Pryor et al. 1972). In all these cases, tannins occurred at high levels (15–30% leaf dry weight). High tannin level have also been observed in a common Southeast Asian shrub, *Clidemin hirta* (Lowry, Thahar et al. 1983).

Phenolics

The most widespread, abundant, and varied plant secondary compounds are the phenolics. They are discussed here not because they usually present toxic problems, but because of their abundance in tropical woody species, the variety of possible effects, and the frequent confusion about their chemical nature and methods of analysis. Phenolics frequently occur at levels of 10–20% leaf dry weight in tropical shrubs (Lowry, Thahar 1983; J.B. Lowry, unpublished) and range from 13 to 50% in 17 species that are valued East African browse plants (Reed 1986). Overall, phenolics probably form the major constraint on the use of shrubs for browse through their effects on intake and digestibility.

Phenolics are defined chemically by the presence of free hydroxyl groups on an aromatic ring. The simplest, such as phenol itself, are toxic and grossly irritant or corrosive to tissue. The majority of phenolics in plants are of somewhat more complex structure and lack such direct effects. They can be broadly classified as those that precipitate protein (tannins) and those that do not. Tannins are formed by two different pathways, giving "hydrolyzable tannins" or "condensed tannins." Apart from some hydrolyzable tannins and a few individual compounds (e.g., rotenone), phenolics have low mammalian toxicity. Most have broad-spectrum antimicrobial activity (which could affect rumen fermentation rate) and some are enzyme inhibitors. Tannins can precipitate digestive enzymes and salivary mucoprotein. They have adverse effects on intake and digestibility at high levels (above 10% leaf dry weight) but are tolerated at up to 5% (Barry and Duncan 1984). Condensed tannins, which can not depolymerize and are not absorbed, may have a useful role in protecting soluble protein from fermentation in the rumen or in preventing bloat. A major question is the overall effect of those phenolics that are metabolized, absorbed, and finally excreted as conjugates with glycine, glucuronic acid, or sulphate. These substrates for conjugation must come from the nitrogen, energy, or mineral metabolism and, for animals under nutritional stress, would be expected to limit the use of high-phenolic forage.

If working with high-phenolic species, it is obviously desirable to have a profile of the compounds present. This requires at least

- tannin analysis by protein precipitation (e.g., Hagerman and Butler 1978; Bate-Smith 1973),
- vanillin determination for condensed tannins and nontanning flavolans (Broadhurst and Jones 1978), and
- a total phenolic determination, e.g., by the Folin-Dennis method (Ribereau-Gayon 1972).

An apparently attractive method for total phenol determination, precipitation with trivalent ytterbium (Reed et al. 1985), cannot be used as such because some common leaf phenolics including the most common flavonol glycoside, rutin, do not precipitate (J.B. Lowry and E.A. Sumpter, unpublished).

Is there a problem?

The concern of this paper is a more effective use of tree forages through overcoming allelochemical effects. The obvious first step is to determine if there is a problem with a particular species. This can be approached either by evaluating animal performance or by chemical analysis.

Animal performance

Acute toxins may give obvious effects that are well known in the areas where the plant occurs. The more general case, however, is harder to evaluate: whether the intake and animal performance is markedly lower than would be expected from proximate analysis (particularly nitrogen and in vitro digestibility) of the plant. Depressed performance is an indication of an allelochemical effect. Species that cause depressed performance include *C. callothyrsus*, *Acacia villosa*, and *Acacia angustissima*, all of which have a high phenolic content (Lowry, Thahar et al. 1983).

Chemical analysis

Certain toxins (e.g., fluoracetate, oxalate, and pyrrolizidine alkaloids) can be detected through chemical analysis. In most cases, once the analysis is set up, rapid screening of many samples is relatively easy. It is much more difficult to look for all possible toxins in a single species. This has obvious implications for collaborative research. However, lesser-known tropical shrubs may contain unknown "antinutrients" — their presence would only be revealed through feeding trials, not by chemical analyses directed to known compounds.

Overcoming antinutrient factors

If there is a problem with allelopathy, the question is how to reduce it. One obvious response is to deal with the plant, perhaps to select for lower levels of allelochemicals or replace it in the feeding system with a more innocuous species. However, plant toxins may be an essential aspect of the plant's fitness for its particular environment. Without them the plant may be much less productive. There were considerable efforts devoted to breeding a "low-mimosine" *Leucaena*. Low-mimosine lines were indeed obtained, but they completely lacked the vigour that was the main attraction of *Leucaena* (Hutton and Bray 1977).

Thus, in general, maximum primary productivity from tree forages in the tropics is to be achieved, we must be prepared to accept that they will contain an array of antinutrients. To get optimum animal performance, the animal rather than the plant must be considered and the ability of the animal to tolerate and use the compounds must be maximized, with or without ameliorative measures. For example, ruminants in Asia are able to detoxify *Leucaena* by rumen microbial activity (Lowry 1983) and it was possible to solve the problem of chronic toxicity elsewhere by transferring the detoxifying microorganisms (Jones and Lowry 1985).

Aversive, nontoxic agents

Sometimes livestock show a low preference for plants that are nontoxic but of high feed quality. *Gliricidia sepium*, for example, is so unpalatable that living fences of it are untouched by livestock and, in most areas, farmers do not cut it for feed because they believe their animals will not eat it. Yet, it is a valued feed in Sri Lanka (Chadhokar 1983) and increasingly so in Bali (Nitis et al. 1987).

There are many references to the toxicity of *Gliricidia* (including that embodied in its generic name), but apparently no specific toxin has been characterized. The aversion response is probably associated with the "mousy" smell, but the nature of the volatiles has also not been determined. The leaf meal certainly has an adverse effect on growing chickens (B. Tangendjaja and J.B. Lowry, unpublished). The responsible toxin appears to have no effect on ruminants, however, and a range of feeding trials have given no indication of toxic effects (Withington et al. 1987). The problem is to induce ruminants to eat *Gliricidia*. One way this can be done is by wilting the material. Other management methods to induce intake include the temporary addition of molasses or salt, supplying for prolonged periods until intake increases, penning with adapted animals, and using old rather than new leaf material.

It is worth emphasizing this case to stimulate the search for others. *Gliricidia* foliage is high in nitrogen and highly digestible. From both existing plantings and its growth performance, the plant is a major resource. It has been totally unused in many areas where it now seems likely to make a valuable contribution to animal production. Are there other highly productive species whose feed value is constrained by palatability alone?

Supplementation

Animal performance on certain forages can be markedly improved by providing appropriate supplements. This has a biological basis in the pathways by which the compounds are metabolized and excreted. Most toxic compounds after metabolism in the liver or other tissues are excreted as conjugates with glycine, glucuronic acid, or sulphate. Clearly, this imposes demands on the available amino acids, glucose, and sulphur, particularly in the case of phenolics because of the high levels that occur in some forage plants. In fact, in *Acacia aneura* (mulga), which contains high levels of phenolics, the positive response to sulphur supplementation has been clearly demonstrated (Gartner and Niven 1978).

Supplements may also prevent the absorption of secondary compounds from the gut. This appears to be the reason for the effect of calcium hydroxide in preventing intoxication by hydrolyzable tannins (Dollahite and Camp 1972). A positive effect from calcium hydroxide has also been found for goats fed the high-tannin shrub *Clidemia hirta* in Indonesia (T.B. Murdiati, unpublished).

Ferric salts have been used to reduce the uptake of mimosine and DHP from *Leucaena*. They also have a positive effect on the use of high-tannin sorghum by poultry. Polyethylene glycol is effective in counteracting the effect of condensed tannins by complexing with them to the exclusion of protein (Barry and Blaney 1987; Pritchard et al. 1988). The current price of polyethylene glycol makes it this uneconomic as a supplement but there is always the possibility of natural analogues (soluble, nondegradable polyhydroxy compounds) occurring in other feed plants, with a positive interaction if the plants were fed together. Finally, activated charcoal can be used as a general agent for binding toxins in the gut.

Although providing supplements may seen impractical in some village farming systems, the low sodium content of tree leaves and, indeed, most forage plants in the humid tropics indicates that optimum growth will not be obtained without salt supplementation (Little et al. 1988). If so, it is reasonable to expect that inexpensive supplements such as elemental sulphur or hydrated lime could be supplied at the same time.

Dilution

A simple approach to reducing toxicity is to feed the toxic plant in mixture with other plants, thus diluting the effective level of each compound. Although simple, this technique may not be easy to perform and depends on the following assumptions:

- Particular compounds have discrete distributions; some are found only in a few related taxa (mimosine), others occur rather widely (condensed tannins).
- Secondary compounds have a diverse chemical nature and, in general, do not interact in their effects on the animal.
- Most compounds have an acceptable level below which no adverse effects are apparent; if so, the plant can be fed safely as a certain proportion of the diet.

For example, when the chronic toxicity of *Leucaena* in Australia was well documented and (before the discovery of rumen microbial detoxication) seen as inhibiting its use, a series of feeding trials showed that it was an extremely useful feed with no toxic problems, providing intake was kept below 40% of the total diet (Jones 1979). Thus, it should be possible to select a set of several species, each containing a different antinutrient factor, none of which can be fed as the sole diet but make an acceptable feed in mixture. Feeding such a mixed diet to ruminants would present practical but solvable problems and could be a simple, rewarding area of research.

The theory has been tested with leaf meal incorporated into the diet of growing broiler chickens. Chickens fed a diet containing leaf meal made by mixing five species (cassava, *Gliricidia*, *Sesbania*, *Leucaena*, and *Calliandra*) performed better than when the same level of leaf meal from any of the individual species was included in the diet (B. Tangendjaja and J.B. Lowry, unpublished).

Simple detoxication treatments

Enzymes capable of degrading specific secondary compounds often occur with the compound in different structures in the same plant cells and reaction occurs when cell membranes are disrupted. This is the basis of some wilting treatments. Perhaps the best known is the wilting of cassava leaves; the cyanogetic glycoside comes in contact with hydrolases, and free hydrogen cyanide is formed and lost by diffusion from the leaf. This postharvest wilting is regularly practiced in areas where cassava tops are fed at high levels. In the field, cyanogetic strains of sorghum wilting under water stress actually accumulate higher levels of cyanogetic glycosides.

In the case of *Leucaena*, wilting of leaves causes the enzymic hydrolysis of mimosine to 3,4(1H)pyridone, eliminating the acute but not the chronic toxicity. The same change occurs rapidly when leaves are dipped in water in a quite narrow temperature range; high enough to induce plasmolysis within the cell but not high enough to denature the enzyme (Lowry, Maryanto et al. 1983).

Simple heat treatment may also reduce toxicity, as in the case of the irritant compounds in leaves of the Araceae. Those of the vigorous but highly irritant *Alocasia macrorhiza* are boiled for feeding to swine in some parts of Asia.

Minimizing toxicity through management

In many plants, the level of secondary compounds is higher in new or developing leaves than in mature leaves. There is no survey publication to support this as a general assertion, but it certainly applies to mimosine in *Leucaena* leaves (Anon. 1984), phenolics in many tropical trees (Lee and Lowry 1980), and the tannins of oak leaves (Pigeon et al. 1962), and has been claimed to be generally true for browse shrubs (Malechek and Balph 1987).

Such a distribution would be consistent with the defensive role of secondary compounds — new leaves, with higher nitrogen, higher cell contents ratio, and lower lignification, are a higher quality feed source. However, following maturation there is relatively little change in feed quality for most tree leaves and certainly no drastic decrease such as occurs with tropical grasses.

Although some tropical plants show continuous leaf development, in others it occurs in discrete flushes weeks or months apart or in response to seasonal change. This suggests that the material is best fed between leaf flushes, when young leaf is at a minimum. It coincides nicely with the use of tree leaves as a supplement at the end of the dry season, as in Bali (Nitis et al. 1987). Also, cutting or browsing may stimulate a flush of new growth, which may, therefore, contain more antinutrients than the uncut material. This has been seen as a "response to browsing" by the shrub (Malechek and Balph 1987). It certainly suggests another factor to be considered when shrubs are being subjected to regular cutting for fodder: cutting interval may affect toxicity.

As previously noted, some species may produce more secondary compounds under nutrient stress and levels can be reduced by fertilization. For such species, the economics of applying fertilizer would be affected not only by increased yield but also by increased feed quality.

Detoxication by rumen microbial activity

In herbivores with foregut fermentation, the initial fermentation stage provides a powerful means for modifying and degrading plant secondary compounds before they can be absorbed from the tract. Thus, ruminants can safely eat many plants that are toxic to hindgut fermenters such as the horse.

The overall chemical environment of the rumen results in many reductive and hydrolytic reactions. The enhanced toxicity resulting from reduction of nitrate to nitrite should not obscure the fact that the majority of such changes decrease biological activity. As well, microbial metabolism can be responsible for specific reactions. When first feeding a plant with a compound that acts as a substrate for rumen microbial metabolism, there may be a lag period while the appropriate microbes accumulate. There is thus a possibility of initial intoxication until the microbe population has adapted to the new feed. This is true in the case of oxalate (Allison 1985).

Until recently, it was accepted that the full range of possible microorganisms could be acquired by the animal from its environment anywhere in the world. Thus, any detoxication process that did not occur on prolonged feeding could not occur. This picture was dramatically changed when it was shown that rumen organisms able to completely detoxify *Leucaena* were apparently endemic in much of Asia, but were absent in Australia and Africa, and that the problem of chronic intoxication in Australia could be solved by the intraruminal infusion of these organisms (Jones and Lowry 1984; Jones and Megarrity 1986).

This finding has wide implications. Other plant allelochemicals that present a problem for animal production may be degradable by organisms that already exist somewhere and can be transferred to domestic ruminants. There are two requirements for this to be possible:

- the compound must be capable of being degraded with some benefit to microbial metabolism (this requires formation by as few as possible reversible steps from primary metabolites), and

- the compound and plant must be present continuously in sufficient amount for plant–animal–microbial coevolution to produce the necessary specialization.

There is currently considerable interest in the nature of the next case that will be susceptible to this solution. The possibility of obtaining new rumen organisms with specific detoxicating ability by recombinant DNA techniques widens the horizon even further.

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Discussion

Session II addressed the utilization of shrubs and tree fodders by ruminants and nonruminants. Three papers were presented on this theme.

The first paper, presented by Dr Devendra, focused on the utilization of these feed resources by ruminants (buffaloes, cattle, goats, and sheep). He emphasized that these potentially valuable feeds are very underestimated, and that the main reasons for this are the development of feeding systems that mainly involve grasses, limited information on the nutritional value of shrubs and fodders, overemphasis on the chemical treatment of cereal straws, and lack of attention to developing innovative feeding systems to support herbivores in the climatic extremes of the tropics.

Apparently, most feeding systems are confined to the use of 13 plant species. Dr Devendra questioned whether these species are priority plants or simply more accessible to researchers. He referred to the use and importance of browse, which is a term used to refer to the tender shoots, twigs, and leaves of shrubs and trees. Browse is particularly valuable to goats and camels in the arid and semi-arid regions.

There is a great need to assess the potential of feed resources and some priority must be given to research in this area. On the animal side, much more information is required on the nutritive value of these feeds, efficient methods of using them, rates of productivity, biomass structure, palatability, feeding behaviour, thresholds of tolerance, production responses, and deleterious principles.

Following this presentation, discussion centered on the tolerance of animals to deleterious principles and the use of green fodders as supplements. The latter was particularly justified because of consistently reduced costs of production.

The second paper in this session, presented by Dr Lopez, concerned the situation with nonruminants. Tree leaf meals were highlighted as important protein and pigment supplements in diets for poultry and pigs. Among the leaf meals, *Leucaena leucocephala* and cassava (*Manihot esculenta*) were the most widely used. However, the production of leaf protein has problems associated with processing and the high cost of production. Leaf protein concentrates were mentioned, but their high costs limit any wide use. The reference to the use of two main leaf meals by nonruminants led to the suggestion that there should be a wider evaluation of other alternative feeds from shrubs and tree species.

The third paper, presented by Dr Lowry, covered the problems of toxic factors and methods of alleviating them in animals. Dr Lowry indicated that the mortality in animals from plant toxins is generally higher in extensive than in intensive systems. These losses resulted from reduced intake or digestibility, or induced deficiencies and harmful side effects.

The major thrust of this paper was that shrub and tree legumes often contain protective secondary compound such as phenolics. Dr Lowry suggested that because of the wide range of toxins and difficulties in analysis, it is not feasible to survey plant genotypes before their evaluation. Animal performance tests are, therefore, a more feasible alternative, including methods to overcome antinutritional factors in feeds.

Discussion centered on practical methods of reducing adverse factors, and methods and costs of analysis. It was pointed out that means of overcoming adverse problems include mixing tree fodders, wilting, using supplements, and introducing new or adapted microorganisms.

Session III

The Three-Strata Forage System

The concept and development of the three-strata forage system

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Abstract *— Three-strata forage system (TSFS) refers to planting and harvesting forages so that a source of feed is available year-round. The first stratum consists of grasses and ground legumes for use during the wet season. The second stratum consists of shrub legumes primarily for use during the middle of the dry season. The third stratum consists of fodder trees for producing feeds during the late dry season. The technology developed in TSFS integrates cash-crop and livestock production. TSFS technology is transferred through training courses, the do-it-yourself approach, and regular consultation and discussion with farmers. Delayed integration with cattle, difficulties in getting grass and legume seeds, and high initial establishment costs are the major constraints in the system adopted by the farmers. TSFS increases the feed quantity and quality, the carrying capacity of the land, the supply of firewood, and farmers' income, and reduces soil erosion.*

Résumé *— Le régime à trois espèces fourragères (RTEF) consiste à planter et à récolter des plantes fourragères de sorte à disposer de fourrage toute l'année. La première espèce se compose de graminées et de légumineuses à utiliser durant la saison humide. La seconde comprend les arbustes légumineux qui servent surtout au milieu de la saison sèche. La troisième regroupe les arbres légumineux qui constitueront le fourrage de la fin de la saison sèche. La technologie mise au point pour le RTEF intègre la culture commerciale et la production animale. Cette technologie est transférée aux paysans au moyen de cours de formation, d'un enseignement pratique et de consultations et discussions régulières avec eux. L'application lente de ce régime au bétail, la difficulté d'obtention de graines de graminées et de légumineuses et les coûts élevés de la mise en place du régime sont les principaux obstacles à son adoption par les paysans. Le RTEF augmente la quantité et la qualité des fourrages, la capacité de charge des terres, le bois de chauffe disponible, les revenus des paysans tout en réduisant l'érosion des sols.*

Resumen *— El sistema de forraje en tres capas (TSFS), trata de la plantación y cosecha de forrajes de manera que haya disponibilidad forrajera durante todo el año. La primer capa consiste en gramíneas y legumbres para usar durante la estación de lluvias. La segunda capa consiste en arbustos leguminosos para utilizar principalmente a mediados de la estación de sequía. La tercer capa consiste en árboles forrajeros para producir piensos durante la última parte de la sequía. La tecnología desarrollada en el TSFS integra cosecha comercial y producción ganadera. La tecnología TSFS se adquiere mediante cursos de formación, con el método "hágalo usted mismo," y consultando regularmente a los granjeros. Las mayores limitaciones del sistema adoptado por los granjeros consisten en la integración tardía con el ganado vacuno, las dificultades para obtener semillas de legumbres y* *gramíneas, y los altos costos de implantación inicial. El TSFS incrementa la cantidad y calidad del forraje, la capacidad de la tierra para nutrir el cultivo, el abastecimiento de leña y los ingresos de los granjeros, a la vez que reduce la erosión del suelo.*

A survey carried out in Bali, Indonesia, showed that, during the wet season, cattle feeds consisted of 14% shrubs and tree fodders; during the dry season, the shrub and tree fodder portion increased to 32% (Nitis et al. 1980). Experiments in dryland farming area in Bali showed that Bali cattle fed 89% grasses supplemented with 11% shrubs and tree fodders gained 58% more live weight than those cattle fed grass only (Nitis 1981). This paper describes the concept and development of the three-strata forage system (TSFS) in Bali.

Background

Most farmers in Bali are smallholder traditional farmers. In the wetland farming area, cash crops are grown continuously or in multiple cropping systems, so that fallow land does not exist. In the dryland farming areas, however, cash crops are grown during the wet season; during the dry season, after the cash crops are harvested, the land is either bare or invaded by volunteer herbaceous species. Growing food crops is the main activity; livestock production, which is always integrated into the system, is a sideline activity. No land is specifically designated for livestock feeds. Ruminants are fed crop residues, grasses and shrubs grown on the edges of the field, and leaves of trees grown for fruit, shade, and protection on the land not suitable for cash-crop production. Often feed for livestock is in short supply, particularly during the dry season.

Selected castration, mass vaccination, export/interisland quota, artificial insemination, and the Kereman, PUTP (five ways to improve farm animals for slaughter), and PIR (nucleus enterprise for farmers) programs are some of the policies and programs that have been implemented to increase the production and population of Bali cattle. Planting grasses and shrub on the terrace and perimeters of the field and on the land not suitable for cash-crop production and demonstration plots to produce cuttings and seeds are some of the efforts of governmental and nongovernmental organization to increase the forage supply in Bali.

Concept of TSFS

TSFS is a technology of planting and harvesting grass, legumes, shrubs, and trees so that a source of livestock feed is available year-round. The first stratum consists of grass and ground legumes, used mainly as livestock feed during the wet season. The second stratum consists of shrub legumes, used mainly for livestock feed during the middle of the dry season. The third stratum consists of fodder trees, which are used for livestock feed late in the dry season.

By incorporating legumes into TSFS, soil fertility increases because of the nitrogen supplied by root nodules. This results in an increased nutritive value of the forage, especially the crude protein content of the foliage.

Description of TSFS

One unit of TSFS covers 0.25 ha and consists of a 0.16-ha core area, a 0.09-ha peripheral area, and a 200-m circumference (Fig. 1). The core area is located in the centre of the plot. It is planted with cash crops (e.g., corn, soybean, and cassava) commonly grown by farmers.

The peripheral area is a 5 m wide buffer zone located between the core and circumference. It is subdivided into 45-m^2 lots (9 m × 5 m). Each lot is planted with buffel grass (*Cenchrus ciliaris* cv. Gayndah), common stylo (*Stylosanthes guianensis* cv. Graham), green panic (*Panicum maximum* cv. Trichoglume), centro (*Centrosema pubescens*), and caribbean stylo (*Stylosanthes hamata* cv. Verano), in that order. This 900-m^2 improved grass and legume pasture is designated as the first stratum.

The circumference area borders the peripheral area. Fodder trees such as *Ficus poacellie*, *Lannea corromandilica*, and *Hibiscus tilleaceus* are planted at 5-m intervals along the circumference. Planted alternatively between two fodder trees are a total of 50 *Gliricidia sepium* shrubs and 50 *Leucaena leucocephala* shrubs.

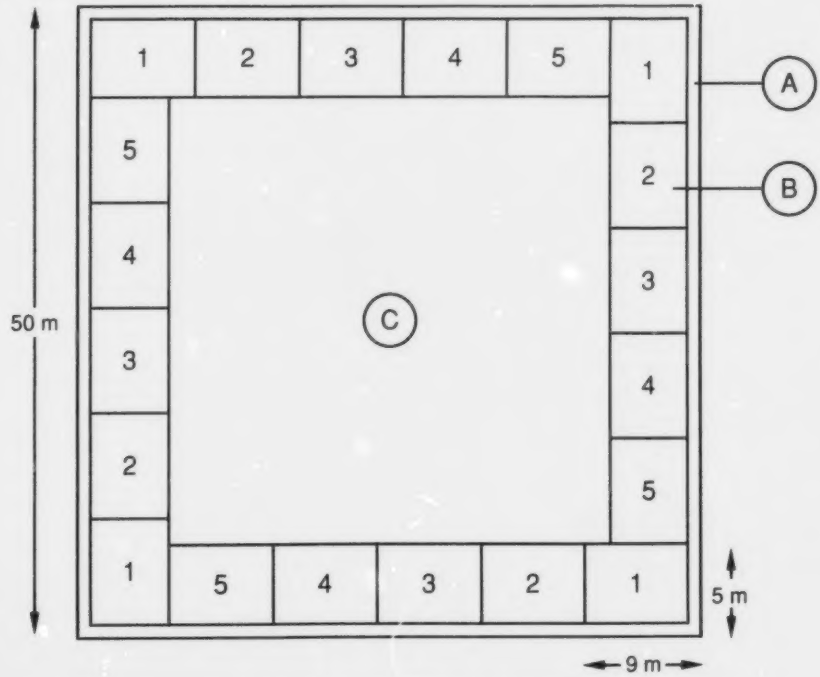

Fig. 1. Circumference (A), periphery (B), and core (C) areas of a TSFS plot. The circumference of the plot is lined with trees (*Ficus*, *Lannea*, and *Hibiscus*) and shrubs (*Gliricidia* and *Leucaena*). The periphery of the plot consists of grasses (1, *Cenchrus*; 2, *Panicum*) and legumes (3, *Stylosanthes guianensis* cv. Graham; 4, *Centrosema*; 5, *Stylosanthes hamata* cv. Verano). The core of the plot contains cash crops (e.g., cassava, peanuts, beans) (source: adapted from Nitis 1984).

The *Gliricidia* and *Leucaena* are designated as the second stratum and the *Ficus*, *Lannea*, and *Hibiscus* trees constitute the third stratum. Together, they from a hedgerow fence around the TSFS unit. One TSFS unit therefore consists of 0.16 ha cash crops for human use and 0.09 ha pasture, 2 000 shrub legumes, and 42 fodder trees to produce feeds for livestock. Cattle are integrated into the system in the 2nd year.

TSFS application

The application of TSFS centres on its integration of cash-crop and livestock production (Fig. 2). This integration has the following advantages:

- Management will improve because farmers usually go to their fields every day to look after cash crops;
- Livestock will not disturb the cash crop because of the protection of the TSFS hedgerow fence;
- Tethered grazing of the livestock can be minimized because TSFS will supply green feeds year-round;
- Soil fertility can be increased by regularly and evenly spreading barnyard manure from cattle in the field; and
- Cash crops and TSFS provide for the farmer's daily needs and generates extra income and acts as insurance to meet the farmer's unexpected expenses.

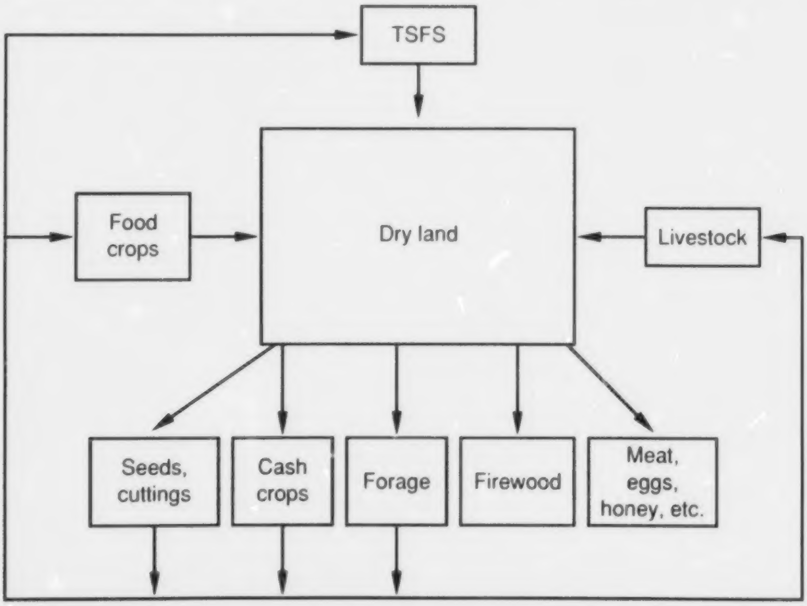

Fig. 2. Mode of TSFS technology application (source: Nitis, Lana, Suarna, Sukanten, and Putra 1988).

TSFS transfer to farmers

Consultation with local government

Before selecting the TSFS site, the following organizations should be consulted (Fig. 3):

- the Provincial Bureau of Planning Board, regarding the master plan of agricultural development,
- the Regency Bureau of Planning Board, concerning priorities for agricultural and livestock development, and
- the head of the village, regarding the location of specific forestry, agriculture, and livestock development programs.

Such consultation is necessary to ensure that the TSFS is in line with existing government development programs and does not interfere with other development programs in progress, and to inform officials of the concept, objectives, and benefits of the project.

Nucleus farmers

Farmers chosen for participation in the TSFS include

- those cultivating their own land, rather than those leasing land from other farmers,
- those who own more than 0.25 ha of land (thus, TSFS will not interfere with established farming practices),

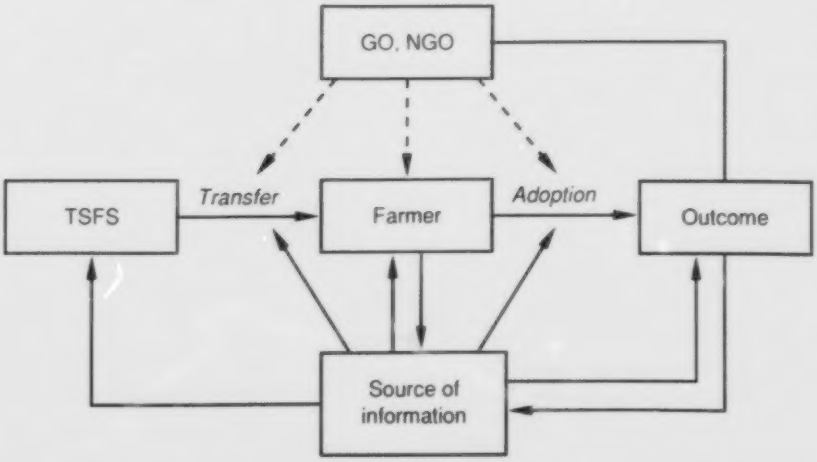

Fig. 3. Mechanism of TSFS technology transfer (source: Nitis, Lana, Suarna, Sukanten, Putra et al. 1988). Solid lines represent direct participation, dashed lines represent indirect participation. GO, governmental organization; NGO, nongovernmental organization.

- those willing to convert 0.09 ha from food-crop to forage production, and
- those who keep livestock for savings and other unexpected expenses that cannot be met by the income from cash crops.

Demonstration plots

In selecting the site, the following points should be considered:

- The steeper the slope of the land, the less the chance for food crops to succeed and the greater the chance of forage development;
- Preference should be given to land with a live fence boundary the shrubs and trees could be used as cuttings for the TSFS; and
- Preference should be given to land currently used for food-crop production rather than to fallow land.

Training course

The training course for the farmers consists of three phases. Phase 1, carried out at the end of the dry season, describes how to select and plough the land, making lots of the first stratum and holes for the second and third strata. It also describes how to plant the grass, ground legumes, shrub legumes, and fodder trees. Phase 2, carried out in the middle of the dry season in the following year, describes how to stop the neighbour's livestock from entering the TSFS, how to manage the seed set and the branches so that they can be used to start another TSFS in the following year, and how to refrain from cutting when the forage is nearly in short supply. Phase 3, carried out early in the wet season, describes how to cut the first, second, and third strata so that feed is available year-round. The farmers are instructed how to feed the livestock so that the diet contains balanced nutrients for growth, fattening, or reproduction, and on the possibility of conserving the excess forage in the form of silage or hay. Farmers are also taught the importance of animal health and disease prevention.

Do-it-yourself approach

The objective of dividing the training course into three phases is to ensure that the farmers have the information fresh in their minds when working in the field. Depending on the time available to members of the TSFS team, farmers get attention as a group or individually. The team shows the farmers what to do and asks the farmer to follow by example. When it is apparent that the farmer has understood, the farmer is encouraged to complete the work. A flexible deadline for the completion of the work is arranged.

The team does not necessarily stay on the site all the time; their presence may make some farmers feel uneasy. When revisiting, the team does not directly pinpoint any mistakes that have been made; rather more emphasis is placed on the good things that have been achieved.

Family participation

Even though only the head of the family participates in the training course, the TSFS team should encourage all family members to participate in fieldwork. Such family participation will develop a sense of belonging, so that when the head of the family is attending other functions, the other family members will take the responsibility of the TSFS activity. The role of children should not be underestimated. They will talk with the other children at school and make them aware that grasses, legumes, shrubs, and trees should not be cut indiscriminately, as is done in the public field.

Comparative group control

Some farmers may show interest in TSFS but not have enough people to do the work. These farmers practice the traditional, non-three-strata forage system (NTFS). They are usually good watchers and may pick a few components of the TSFS technology that are suited to their specific location. These farmers may be used as a comparative control to monitor the extent of technology transfer to the TSFS farmers.

Contact person

To attend to the day-to-day activities of farmers and to bridge the communication gap between the farmers and the TSFS team, a contact person in the TSFS location is needed. This contact person should be well trained, conversant with the various technical aspects of agriculture, able to make decisions, act quickly, and report immediately to the team. The team should ensure that the contact person does not become too bossy for the farmers.

Farmers' group formation

If a farmers' group has already been formed, either a member of this group or members of some other groups can form a TSFS group. If no farmers' group exists, a TSFS farmers' group should be formed. The group should consist of farmers actively participating in TSFS as well as those interested in TSFS (NTFS farmers).

The TSFS activity should only be part of the group activities. Family planning, child care, health programs, and home industry should also be included. The farmers' group may set rules and regulations and enforce them by setting a penalty for those who do not follow these regulations.

Guidance and consultation

The TSFS team and the farmers should meet regularly to discuss any problems that have arisen and seek solutions that are beneficial to the farmers. Problem solving through personal contact is preferable to problem solving by vote. The team should listen, consider, and acknowledge the farmers' suggestions.

Farmers' opportunity for selection

Using three varieties of grasses, three varieties of legumes, two varieties of shrubs, and three varieties of trees, and planting them individually, will allow the farmer to select the plant best suited to the location. Farmers can also select the cattle or goats to raise in the system. If farmers need draft power, cattle are appropriate. If farmers need quick cash, goats are more appropriate. Planting arrangements can also be varied to suit the farmer's needs. For fence lines, *Gliricidia* and *Lannea* are appropriate.

Incentives to farmers

The following incentives are given:

- In each 0.25-ha plot, the farmer loses 0.09 ha for food-crop production the farmer is compensated for this lost production.
- Farmers must use the 0.09-ha area and make holes for the shrub and trees seeds and cuttings are given free of charge to the farmers.
- When cattle and goats are sold, each farmer receives 50% of the profits after the initial cost of the livestock has been deducted from the cost of the animals.

Observing local customs and traditions

When starting a new component technology, farmers should be consulted to avoid any inconvenience to them or their surroundings. For example, some farmers prefer *Ficus* to be planted away from the house because its shallow root system may interfere with the house's foundation. Farmers will not castrate cattle during the wet season because flies will infect the wound. An offering is made in Bali before beginning castration.

The team attitude

Each team should bear in mind the following points:

- Their function is to solve farmers' problems, not to solve the problems in the research project.
- The farmers have the knowledge, the team has the science.
- Farmers must feel that the team belongs to them, not that they belong to the team.

Governmental and nongovernmental participation

Apart from consulting government officials regarding TSFS, the team should ask governmental and nongovernmental organizations to visit the site and talk to the farmers. Interested governmental organizations will help to spread the idea of TSFS. When appropriate, newspaper, radio, and television should be used to make other farmers aware of the TSFS technology (see Fig. 3).

Constraints in the adoption of TSFS

In transferring TSFS technology to the farmers, three constraints merit special attention (Nitis et al. 1986). First, farmers must wait 1 year for the establishment of the first and second strata and 3 years for the establishment of the third stratum. However, the loss of 0.09 ha for cash-crop cultivation will be compensated for by the sale of cattle. Second, drought-resistent grasses and ground legumes are difficult to obtain when TSFS is newly introduced to another area. However, once they are established, they become a source of planting material and seeds for other farmers interested in adopting TSFS technology. Third, the initial establishment cost of 150–200 USD is expensive for farmers. Through special bank loans and cooperative arrangements, however, such an investment can be made without upsetting the budget of farmers.

Improving the TSFS concept

To improve the TSFS concept, the following developments have been made:

- 'Graham' stylo, a volunteer cultivar, is replaced with *Urochloa mosambisensis*, which is more persistent.
- *Centrosema*, a creeping legume, is planted with *Stylosanthes scabra* cv. Seca to act as climber for the *Centrosema*.
- Because *Leucaena* yield is low (as a result of infestation by *Heterphsylla cubana*), *Acacia villosa* is sown along the *Leucaena* row.
- Because terraces could reduce the use of the sloping land, shrub legumes are planted along the lower side of the terrace at a spacing of 1 m as well as a strip of mixed grass and legume 1 m wide.

Expected outcome

The expected results of TSFS are as follows:

- decreased cash-crop yield (the land used to grow cash crops is reduced to 0.16 ha from the 0.25 ha provided);
- increased livestock feed (each unit of TSFS consists of 0.09 ha improved pasture, 2 000 shrub legumes, and 42 fodder trees);
- improved livestock feed (ground and shrub legumes are included in the system);
- increased carrying capacity of the land (extra forages are available);
- faster cattle growth, particularly during the dry season, when feeds are usually in short supply;
- increased firewood supply (branches of shrubs and trees are not fed to livestock);

- reduced soil erosion (first, second, and third strata reduce rainwater runoff);
- less time spent managing cattle (feed is always available);
- increased bee keeping and honey production (plants in all three strata do not flower simultaneously);
- increased "Kampung" chicken production (white ants roaming on the leaf debris, grass seeds, and legume seeds are sources of protein and carbohydrates for the poultry);
- increased farm income; and
- greener countryside (all strata are green almost year-round).

Extent of TSFS adoption

Most farmers will find no difficulty in adopting the TSFS technology. The classification of TSFS into core, peripheral, and circumference areas should be familiar to the farmers they usually construct a live fence around the field and cannot plough close to the fence, therefore, a belt of native grass is always found between the cash crop and the fence. Also, using two grass and three legume species for the first stratum, two shrub legume species for the second stratum, and three fodder tree species for the third stratum will give the farmer ample opportunity to select preferred species.

When initiated in 1984, 32 TSFS units were established. In 1986, the Provincial Bali Government initiated 30 TSFS units in east Bali (Nitis et al. 1987). In 1987, the Daya Pertiwi Foundation initiated 12 TSFS units in Nusa Penida (Nitis, Sukanten et al. 1988); in October 1988, they increased this total by another 37 units. The Foster Parent Plan International Bali initiated 30 TSFS units in east Bali in October 1988. The Badung regency plans to initiate 34 TSFS units in south Bali in 1989. TSFS could also benefit farmers in other parts of Indonesia as well as the rest of Asia and in Africa.

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Research protocols appropriate to the development of methodology for the three-strata forage system

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Abstract *— Three-strata forage system (TSFS) research protocols consist of objectives, design, site and farmer selections, forage system, stocking rate, soil status, climatic condition, and statistical analysis. Because the TSFS approach is integrated, the methodology is based on assessing forage quantity and quality, cattle feeds and feeding, soil erosion, the interrelation among grasses, ground legumes, shrub legumes, and fodder trees, and the interrelation among climatic factors, topography, and forage yield. These assessments also allow for the measurement of food, feeds, firewood, carrying capacity, and environment conservation. To assess the full benefit of fodder trees as feed sources, such studies should be carried out for at least 6 years.*

Résumé *— Les protocoles de recherche sur le régime à trois espèces fourragères (RTEF) consistent à déterminer les objectifs, le plan et le site de la recherche, à choisir les paysans, à établir le système de fourrage, le taux de charge, l'état des sols, les conditions climatiques et à faire des analyses statistiques. Parce que le RTEF est un régime intégré, la méthodologie se fonde sur l'évaluation de la quantité et de la qualité des fourrages, des aliments et de l'alimentation du bétail, de l'érosion des sols et de l'interrelation entre les graminées, les légumineuses, les légumineuses arbustives et les arbres fourragers comme l'interrelation entre les facteurs climatiques, la topographie et le rendement des fourrages. Cette évaluation permet aussi de mesurer les cultures vivrières, les plantes fourragères, le bois de chauffe, la capacité de charge et la conservation de l'environnement. Pour bien évaluer pleinement les avantages des arbres fourragers comme source de fourrage de telles études doivent s'étendre sur au moins six années.*

Resumen *— Los protocolos de investigación del sistema de forraje en tres capas (TSFS) consisten en objetivos, proyecto, selecciones de lugar y granjero, sistema de forraje, densidad de pastoreo, estado del suelo, condición climática y análisis estadístico. Como el TSFS es una técnica integrada, la metodología se basa en la evaluación de calidad y cantidad de piensos y alimentación del ganado vacuno, erosión del suelo, interrelación entre gramíneas, legumbres, arbustos leguminosos y árboles forrajeros, así como entre los factores climáticos, la topografía y el rendimiento del forraje. Estas evaluaciones también permiten la medición de productos alimenticios, forraje, leña, capacidad de carga y protección del medio ambiente. Para efectuar la evaluación de todos los beneficios que reportan los árboles forrajeros como fuentes alimenticias, deben llevarse a cabo dichos estudios por lo menos durante seis años.*

Introduction

In the traditional farming system in dryland areas in Bali, food crop production is the main activity; livestock production is a sideline. The concept of the three-strata forage system (TSFS) has been described by Nitis et al. (this volume). In TSFS, forage, food crop, and cattle complement each other. The research methodology was aimed at answering the broad and specific objectives of TSFS. This paper describes the research protocols, methodology, and productivity of TSFS.

Research protocols

Objectives

The overall objective of TSFS is to increase farmers' incomes through improved land management involving crop–animal systems. The specific objective is to define a three-strata production model for food and feed for the semi-arid rainfall areas of Bali. This is done by

- evaluating growth and yield of grasses, legumes, shrubs, trees, and crop components;
- measuring the nutritive value of the feed sources produced in the system;
- measuring the performance (growth, feed intake, and carcass quality) of Bali cattle;
- evaluating carrying capacity; and
- comparing the economic and ecological advantages of TSFS to the existing traditional system (non-three-strata forage system, NTFS).

Design

The factorial design is a completely randomized arrangement consisting of two forage systems (strata and nonstrata), two stocking rates (2 and 4 cattle/ha), and 11 and 10 replications for the low and high stocking rates, respectively.

Site selection

The site is a dryland farming area in the semi-arid climatic zone (4 months wet and 8 months dry), with emphasis on cattle development. The site is also outside the area designated for industrial and tourist development. The topography is undulating, with 30% flat area and 70% sloping area.

Farmer selection and participation

The farmers selected own more than 0.25 ha of land, till their own land, raise cattle, own water catchments, are members of farmers group, are willing to surrender 0.25 ha of land to forage production, and participate actively in the project. Of the 26 farmers selected, 12 were for TSFS and 14 were for NTFS. Each farmer looks after at least one plot and, at the most, four plots.

Forage system

Plot allocation

The 20 ha of land was divided into 8-, 8-, and 4-ha areas for TSFS, NTFS, and tether grazing, respectively. Another 0.25 ha was allocated for cattle weighing, the forage nursery, and demonstration purposes.

The TSFS and NTFS area was divided equally into 50 × 50 m (0.25 ha) plots (each plot was not necessarily square — it is difficult to get a uniform layout). Therefore, there were 64 plots of 0.25 ha each in the 16-ha area. Because of the undulating topography, 22 plots were sloping (S), 22 were flat (F), and 20 combined flat and sloping land (FS).

Forage and cash crop allocation

The allocation of cash crops in the core area, the first stratum in the peripheral areas, and the second and third strata in the circumference area of the TSFS have been described by Nitis et al. (this volume). The 0.25-ha NTFS plot was not divided into core, peripheral, and circumference areas. Instead, the entire area was planted with cash crop. Four tree fodders were planted at the corners of the NTFS as a boundary.

Planting and establishment

After ploughing and harrowing the land, cuttings of ficus (*Ficus poacellie*), lannea (*Lannea corromandilica*), and gliricidia (*Gliricidia sepium*) were planted at the onset of the wet season (end of October). Hibiscus (*Hibiscus tilliaceus*), however, were planted in the wet season; planting during the dry season would cause the stems to dry and peel. Buffel grass (*Cenchrus ciliaris* cv. Gayndah), green panic (*Panicum maximum* var. *trichoglume*), legume centro (*Centrosema pubescens*), common stylo (*Stylosanthes guianensis* cv. Graham), Caribbean stylo (*Stylosanthes hamata* cv. Verano), and leucaena (*Leucaena leucocephala*) are planted as seeds after the appropriate scarification during the wet season (December). Resowing and replanting are carried out 1 or 2 months after planting. The plants are then allowed to establish for 12 months. The corn, soybean, and cassava are planted simultaneously in November every year. Corn is harvested in February, soybean in March, and cassava in July, as is commonly done by farmers.

Stocking rate arrangement

Because the land is divided into 0.25-ha units instead of 1.0-ha units, the stoking rate was arranged according to the 0.25-ha plot size. That is, the 2 cattle/ha stocking rate is equivalent to one head of cattle for two plots (0.5 ha). The 4 cattle/ha stocking rate is equivalent to one cow per 0.25-ha plot. When two plots are allocated for one cow, the plots are contiguous.

Of the 50 cattle bought in the local market, 21 were for TSFS (10 for the higher stocking rate, 11 for the lower stocking rate), 21 were for NTFS, and 8 were raised traditionally.

Soil status

The limestone-based soil is a red brown Mediterranean type (Winaya et al. 1980). The F, S, and FS plots contained 2.78, 2.97, and 2.21% organic matter, and 0.045, 0.299, and 0.159% total nitrogen, respectively.

Climatic condition

Rainfall was recorded daily at the centre of the project site. The temperature and relative humidity was recorded by a thermohydrograph, also at the centre of the project site.

Statistical analysis

The parametric data was analyzed using the analysis of variance (Steel and Torrie 1960); nonparametric data was analyzed with the χ^2 test (Gomez and Gomez 1976). Where appropriate, data were subjected to regression analysis (Sokal and Rohlf 1969).

Development of TSFS methodology

Forage

For the grass and ground legume used as samples, 0.5 × 0.5 m quadrats were used. Marked with iron rods, each quadrat is located 1 m from the shrubs and the trees and is on the border of the adjacent grasses, legumes, and cash crops (see Fig. 1 in Nitis et al., this volume, p. 94). For shrub legumes, one plant in the middle of the row and two plants 1 m from the adjacent tree are tagged with a zinc plate. For fodder trees, those opposite the quadrat and those 1 m from the selected shrub legumes are used as samples. The quadrat and the tag in F, S, and FS plots were arranged so that each treatment was replicated 9 times.

Grasses and ground legumes were cut at 15 cm, leucaena at 1 m, and gliricidia at 2 m heights. The fodder trees were lopped at average branch level. Cutting and lopping were done twice a year: at the end of the wet season (mid-March) and at the end of the dry season (mid-November). For the grasses and ground legumes, the density, weed infestation, height, and fresh weight were recorded. For the shrubs and trees, height, length of lopping, number of branches, number of leaves, and fresh weights of the branch and leaves were recorded. A 100- to 500-g subsample from each observation was taken for dry weight determination. Samples were dried in a forced-draught oven at 70°C to a constant weight.

Forage yield

The 4th-year harvest (Nitis et al. 1987) gave the following results:

- Yield of the first stratum was higher than that of the third stratum; yield of the third stratum was higher than that of the second stratum.

- Yield during the wet season (4 months) was higher than that of the dry season (8 months).
- Yield of the sloping (S) plots was higher than that of the flat (F) plots.
- Yield of graham stylo decreased after 3 years of continuous cuttings.
- The lower yield of leucaena was due to *Heteropshylla*. Guzadrin and azodrin spraying was ineffective in controlling this attack.
- Hibiscus did not grow well on the sloping plot.

Association among grasses, legumes, shrubs, and trees

Apart from the forage shoot yield sample, nodules in the soil of the flat plots were taken using an auger at 0–20 cm depth at 25, 50, and 100 cm from the respective shrub legumes at the end of the wet season. The soil was flushed with water and passed progressively through 50- and 10-mm sieves to separate the nodules, roots, and soil. Nodule activity was then evaluated (Skerman 1977).

The results of the 4th-year harvest (Nitis et al. 1987) and the nodulation showed the following:

- There was an interrelationship between the plants in the first, second, and third strata and this interrelationship changed with the season.
- Gliricidia and its association with grasses produced heavier and more nodules. However, the nodules were smaller than those found on gliricidia in association with ground legumes. A similar trend was observed for leucaena.
- At the end of the wet season, nodule activity of shrub legumes varied from 40 to 60%. This activity was unaffected by grass and ground legume species.
- Nodulation on gliricidia decreased markedly away from the main root; on leucaena, however, nodulation is evenly distributed.

Microclimate and forage growth

Where cenchrus was associated with gliricidia or leucaena, quadrat sampling was done at 0.5, 1.0, 1.5, 2.0, and 2.5 m from the middle row of the fenceline. Beside the quadrat, soil moisture, soil temperature, and light intensity under the cenchrus canopy were determined. Similar tests were also carried out for verano stylo.

Soil moisture, soil temperature, and light intensity were recorded in the morning (0700–0900), around noon (1200–1300), and in the afternoon (1500–1600); each measurement was repeated 9 times. Density, tiller number, and the area covered by the cenchrus and verano stylo were recorded at the same time.

The results showed the following (Nitis et al. 1986):

- Soil moisture and soil temperature under cenchrus and verano stylo canopies are unaffected by association with gliricidia and leucaena.
- Light intensity under the gliricidia canopy in association with cenchrus was lower than that under leucaena. A similar trend was observed for verano stylo.

- The growth (plant density, tiller number, and cover) of cenchrus and verano stylo was affected more by the shading of shrub legumes than by soil moisture or soil temperature.

Rainfall and forage yield

The TSFS experiment was carried out in a dryland farming area with an average annual rainfall of 1 000 mm, with 116 rainy days distributed through the 8-month dry season and the 4-month wet season. The 3 years of data on rainfall and forage yield showed the following:

- The yield of grasses was higher than that of legumes.
- The coefficient of determination for cenchrus was highest; that of panicum was lowest. The effect of the dependent variables varied among forage species.
- The higher yield of cenchrus was due to its greater responsiveness to precipitation; there was enough moisture to sustain a longer growing period.
- The lower yield of legumes was due to its greater responsiveness to the first rain, which is usually insufficient for good regrowth.

Forage conservation

After digging and cutting limestone to make bricks, the holes are left unattended. These holes, with a bit of adjustment to the wall and the dimensions, can be used as a trench silo.

Silage was made with leaves of gliricidia, leucaena, verano stylo, and lannea. Such leaves are not good for hay because the leaf blades shatter during drying. Silage was made in February and used in May 1986 (Nitis et al. 1986). The results showed the following:

- Based on physical characteristics (odour, flavour, colour, and consistency), the silage is good.
- Based on chemical characteristics, gliricidia silage is inferior.
- Gliricidia silage was low in dry matter and crude protein.

Even though the silage was rated good, farmers were reluctant to make it because of the time spent cutting the forage and filling the holes. An alternative method is under consideration.

Cash crops

In the TSFS plot, four samples were taken. Each sample was in the border of either the grasses or the legumes (see Fig. 1, Nitis et al., this volume, p. 94). Another sample was taken in the middle of the plot. For the NTFS plot, four peripheral samples were taken 5 m from the border of the plot and one sample was taken in the middle of the plot. Samples were taken on the flat (F), sloping (S), and FS plots, with nine replications each.

Samples were collected just before cash crop harvest. For soybean, each sample was taken within a 0.5 × 0.5 m quadrat; for corn and cassava, each sample was taken within a 1 × 1 m quadrat. Absolute samples (i.e., yield of each plot) were taken for comparison. Fresh weights of corn and soybean grains, cassava tubers, corn stovers (including the bean peel), and cassava tops (stem and some leaves) were also recorded.

To study the effect of grasses and ground legumes on the cash crop, samples were taken 0.1 and 2 m from the forage border on the top, bottom, and either side of each sloping plot. Four similar sloping plots were selected for replication.

The 4th-year harvest (Nitis et al. 1987) gave the following results:

- In TSFS, yields of the grains, tubers, and straws from S plots were lower than those from F and FS plots. A similar trend was observed for NTFS.
- Corn was affected the most and cassava was affected the least by sloping gradients.
- The cash crop grown in association with panicum produced more grains, tubers, and straws than the cash crop in association with cenchrus.
- The cash crop grown in association with 'Graham' stylo produced more grains, tubers, and straws than the cash crop in association with either verano stylo or centrosema.
- Ground legumes had a greater favorable effect on cash crop than did grasses.
- Corn and soybean yields were unaffected, but cassava yields increased with increasing distance from the forage border (Nitis et al. 1988). The highest cassava yields were 1 m from the cenchrus border.

Chemical composition and nutritive value

The interrelationship between grasses, legumes, shrubs, trees, the three topographies (F, S, and FS), and the nine replications gave a total of 2 079 samples per harvest. For chemical analysis, the number of replications was reduced to three by pooling samples. Dry matter was determined by drying the ground sample at 105°C to a constant weight. The crude protein, gross energy, acid detergent fibre, and neutral detergent fibre contents were determined according to Wolfenden (1982).

The following results (Nitis et al. 1986; Nitis et al. 1987; Nitis et al. 1988) were obtained:

- Topography had no effect on the chemical composition of grasses, ground legumes, shrubs, and trees.
- Plants in the first and second strata had no effect on the chemical composition of plants in the third stratum.
- Plants in the second and third strata had no effect on the chemical composition of plants in the first stratum.
- Plants in the first and third strata had no effect on the chemical composition of plants in the second stratum.

- The chemical composition of soybean straw and cassava leaves were not affected by the association of the plants with grasses and legumes.

In vitro dry matter digestibility

Twelve 2-kg samples of forage, offered to the cattle, were collected every 28 days (Nitis et al. 1986). The 12 samples consisted of 6 samples from TSFS and 6 from NTFS cattle. Each group of 6 samples consisted of 3 samples from the high stocking rate and 3 from the low stocking rate. The three samples from the low and high stocking rates were associated with the three topographical conditions (F, S, and FS).

Three replicate samples of cenchrus, panicum, centrosema, and verano stylo under low and high stocking rates and the three topographical conditions were taken at the end of the wet season (March 1988) (Nitis et al. 1988). The technique used is that of Jones and Hayword (1975) adapted by Goto and Minson (1977) using 2.5% cellulase (Onozuka SS p-1500). The following results were obtained:

- Season had no effect on the dry matter digestibility (DMD) of the cattle diet.
- DMD of TSFS cattle diet was 5% higher than that of NTFS cattle diet.
- DMD of the cattle diet from F and FS plots was 12–14% higher than that from the S plot.
- The DMDs of grasses and two legumes at the high stocking rate were slightly higher than those at the low rate. DMDs of the two grasses and the two legumes in the F plots was slightly higher than those in the S plots. These differences were not significant.

Allelophatic factors

The growth of cenchrus with gliricidia was not as good as its growth under leucaena. The possibility of the presence of an allelophatic factor was examined. Extracts of fresh gliricidia leaves and roots and the soil under gliricidia were used in solution to water cenchrus plants (in plastic pots in a greenhouse). The experiments were replicated six times. The cenchrus watered with extract of gliricidia soil produced fewer leaves and tillerers and lower shoot yield than those watered with the other extract solutions (Nitis et al. 1987).

Deleterious substances

In a mixed diet, gliricidia consumption by cattle was 40–60%; when gliricidia was fed alone, consumption was 76%. The possible presence of deleterious substances affecting palatability and intake was studied by taking 250-g leaf samples from the top and bottom branches of gliricidia grown in association with cenchrus, panicum, centrosema, or verano stylo on flat and sloping plots. Samples were taken at the end of the wet season (March 1987). Specific compounds were determined spectrophotometrically by the HCl–vanillin method (T. Horigome, personal communication).

The following results were obtained (Nitis et al. 1988):

- Flavonol content is higher in younger leaves than in older leaves.
- Gliricidia leaves from the S plot contained more flavonol than those from the F plot.
- The highest flavonol content was found in the leaf grown in association with centrosema on the S plot; the lowest content was found in the gliricidia grown in association with panicum on the F plot.
- Catechen and total phenol contents were unaffected by these parameters.

Cattle performance

Live weight gain and feed conversion

The average initial live weight of castrated Bali steers was 122 kg. Each steer was weighed every 28 days. For TSFS, forage are cut from the allocated plot and cattle are stall-fed continuously. The botanical composition on the feed offered depends on the season and the availability of the plant species. Generally, during the wet season, the diet consisted of 75% grasses and ground legumes and 25% shrub legumes and tree fodders. During the dry season, the diet consisted of 25% grasses and ground legumes and 75% shrub legumes and tree fodders. For NTFS, cattle were tethered and grazed during the day and stall-fed at night with the forage cut from the allocated plot.

One week before weighing, the amount and botanical composition of the feed offered and refusals were assessed. The daily feed requirement was estimated at 3% (DM) of average live weight plus 5% for ad libitum feeding.

The study gave the following 4-year results (Nitis et al. 1987):

- Live weight gain during the wet season was higher than during the dry season.
- TSFS cattle gained 8% less weight during the wet season and 17% more weight in the dry season than NTFS cattle.
- During the wet season, cattle at the higher stocking rate gained weight the same as cattle at the lower stocking rate. During the dry season, however, cattle at the low stocking rate gained 17% more weight than cattle at the high rate.
- Over the past 2 years, TSFS cattle gained 7% more weight, consumed 31% less forage, and were 35% more efficient in using forage than NTFS cattle. A similar trend was observed for cattle at the low stocking rate compared with those at the high stocking rate.

Feeding behaviour

Six cattle each from TSFS and NTFS were selected. For TSFS, cattle were observed in the stall; for NTFS, cattle were observed tethered. Cattle were observed for 12 h (0600–1800); the study was repeated three times. The following results were obtained (Nitis et al. 1987):

- Stall-fed TSFS cattle spent less time sniffing and eating the feed than tethered NTFS cattle.

- TSFS cattle spent more time ruminating and chewing than NTFS cattle.
- TSFS cattle spent more time urinating than NTFS cattle; times spent defecating were similar for both groups.
- TSFS cattle rested longer and more frequently (either standing or lying down) than NTFS cattle.

Gliricidia preference

When gliricidia was mixed with other forages, the consumption was up to 36% during the wet season and 45% during the dry season for TSFS cattle. For NTFS cattle, the corresponding values were 50 and 66%.

A Latin-square design (four feeding regimes, four cattle) was used to study the preference of cattle fed 100% gliricidia. The feed consisted of young leaves (top half of the leaves on the branch), old leaves (bottom half of the leaves on the branch), whole leaves (mixture of young and old leaves), and rachis (young branches with old and young leaves). The 28-day feeding experiment gave the following results (Nitis et al. 1987):

- Young leaves are less preferable than older leaves, presumably because of their astringent odour.
- Even though the consumption of young leaves is less than that of older leaves, because young leaves contain more CP, CP consumed is about the same.
- Cattle given the rachis feed spent time eating and turning over the feed to get at the older leaves and peel the skin off the young branches.
- Cattle weighing 184 kg (live weight) consumed 13–17 kg/day (fresh weight) gliricidia (1.63–2.17% of body weight).

Soil erosion

In July 1986, 18 months after TSFS establishment, a soil erosion study was initiated. Thirty galvanized iron pipes, each 150 cm long, were placed in the middle of the lots so that 125 cm of the pipe emerged above ground level. A mark was made by sawing a line on each pipe at ground level. This marking represented the starting point (zero reading) of erosion.

The slope selected varied from 8 to 10°. In TSFS, 15 lots (5 × 9 m each) were selected: three lots each of cenchrus, graham stylo, panicum, centro, and verano stylo. In NTFS, slopes similar to those TSFS plots were selected. In each NTFS plot, one to three locations were selected, each covering an area of 5 × 9 m (45 m^2). The study produced the following results (Nitis et al. 1988):

- In the year 1, the extent of erosion in TSFS was 6.56 mm; in NTFS, 12.00 mm. In the year 2, the extent of erosion in TSFS was 10.56 mm; in NTFS, 20.39 mm.
- Erosion in the grass lots was less than that in the legume lots.
- Among grasses, erosion in the cenchrus lots was less than in the panicum lots.

- Among legumes, erosion in the verano stylo lots was the least; graham stylo lots showed the most erosion.

Other studies

Mixed pasture

Because the two grasses (cenchrus and panicum) and three legumes (graham, verano, and centrosema) are grown individually in TSFS, a completely randomized block design with 12 treatments and 6 blocks was initiated in December 1985 to study the growth, yield, and persistency of the two grasses and three legumes in monospecific and mixed pasture. The 12 treatments included 2 grasses (cenchrus and panicum), 3 legumes (graham, verano, and centrosema), 3 cenchrus–legume (cenchrus–graham, cenchrus–verano, and cenchrus–centrosema), 3 panicum–legume (panicum–graham, panicum–verano, and panicum–centrosema), and one complete mixture (cenchrus–panicum–graham–verano–centrosema). Each plot was 5 × 6 m with a 30-cm raised bed in 0.53 ha of land with a 3–5° slope. Another 0.20-ha plot was allocated to compare with the native pasture.

The pasture was allowed to establish for 1 year and cutting was carried out twice a year; at the end of the dry season and at the end of the wet season. Samples (15 cm long) were collected using a 1.0-m^2 quadrat located in the middle of the plot. The whole plot was then cut. At the end of year 2, the following observations were made (Nitis et al. 1987):

- As monospecific pasture, verano stylo gave the highest yield and graham stylo gave the lowest.
- As mixed pasture, cenchrus–centrosema gave the highest yield and cenchrus–verano stylo gave the lowest.
- Wet-season yields were higher than those in the dry season.
- Grasses were more persistent than legumes during the dry season.
- The yield of the mixed pasture was not always higher that its monospecific counterpart.
- The yield of cenchrus was higher when it was grown on its own; panicum yield was higher when it was mixed with legumes.

Gliricidia germ plasm

At the end of the dry season, most of the young foliage of gliricidia was affected by black aphid. To study possible plant resistance, 15 provenances of *Gliricidia sepium* from seven Central American countries (provided by the Oxford Forestry Institute, UK) and one provenance of Indonesia (Bukit Bali) were tested in the field at Bukit. The 16 provenances have been grown in an area with rainfall varying from 600 to 3 500 mm and altitude varying from 0 to 1 100 mm. The location was selected so that the 16 provenances could be tested in alley cropping according to the method of Hughes (1987) and with the TSFS described by Nitis (1984). The alley cropping design is a completely randomized block arrangement with 16 treatments, 6 blocks (replicates), and 12 plants/replication. The three-strata fence design was a stratified, completely randomized block arrangement with 16 treatments, 12 blocks, and 10 plants/replication. Transplanting from the nursery was carried out on 1 December 1987, when the plants were 8 weeks old. Observation at 32 weeks after transplanting showed the following:

- Height, number of leaves, and branching habits varied among provenances.
- Some provenances produced more branches on the ground level, others produced more branches on the top half of the plants.
- Generally, more leaves were produced on the branches; in some provenances, the leaf number on the stem was similar to that on the branches.
- Stem elongation and leaf production not only depended on the provenance but were also affected by season.
- Percentage of leaf retained during the dry season on the branches was higher than that on the stems.
- Interestingly, the local provenance occupied ranking orders 3 to 8 of the 16 orders.

Productivity of TSFS

The 5-year (1984–1988) study clearly demonstrated the importance of the TSFS in terms of food, feeds, firewood, cattle, and conservation of the environment (Table 1).

Food

The lower grain yield of corn and soybean and lower tuber yield of cassava was due to the reduced plot size in TSFS (0.16 ha; that of NTFS was 0.25 ha).

Table 1. Productivity (kg dry weight/plot per year, unless noted) of TSFS and NTFS plots.

	TSFS plot (0.25 ha)	NTFS plot (0.50 ha)
Food	853	1 268
Straw	750	1 218
First stratum	455	—
Second stratum	310	—
Third stratum	15	—
Shrubs	—	132
Trees	—	2
Improved grasses	—	10
Native grasses	—	242
Firewood	1 049	475
Cattle live weight gain (kg/3 years)	186	166
Carrying capacity (cattle/ha)	4	2
Maximum live weight to carry (kg/head per plot)	300	200
Soil erosion (mm/2 years)	11	20

Source: Nitis et al. (1987), Nitis et al. (1988).

Feeds

- The higher straw production of NTFS was due to its larger area (0.25 ha vs 0.16 ha for TSFS).
- The grass and ground legume yields of TSFS were higher than those of NTFS. Of the 16 NTFS farmers, 12 planted cenchrus and panicum over 11 m^2/plot; in TSFS, this area was 45 m^2/plot.
- The 455.4 kg of grass and legume in TSFS occupied only 0.09 ha (5 060 kg/ha); the 241.9 kg of native grass in the NTFS occupied 0.25 ha (967.6 kg/ha).
- The yield of the shrubs and trees in TSFS was higher than that in NTFS. The NTFS plots were formerly surrounded by cactus. Of the 16 NTFS farmers, 12 have now replaced the cactus with gliricidia or leucaena, ficus, and lannea; the NTFS plots now also produce good yields of shrubs and tree fodders.

Firewood

When farmers cut the shrubs and trees in TSFS for fodder, the residual branches become useful for firewood (Fig. 1). The sources of the firewood are as follows:

- regular, daily cutting for forage and
- lopping every 3 years to remove the "head" formed by regular cutting at a certain height.

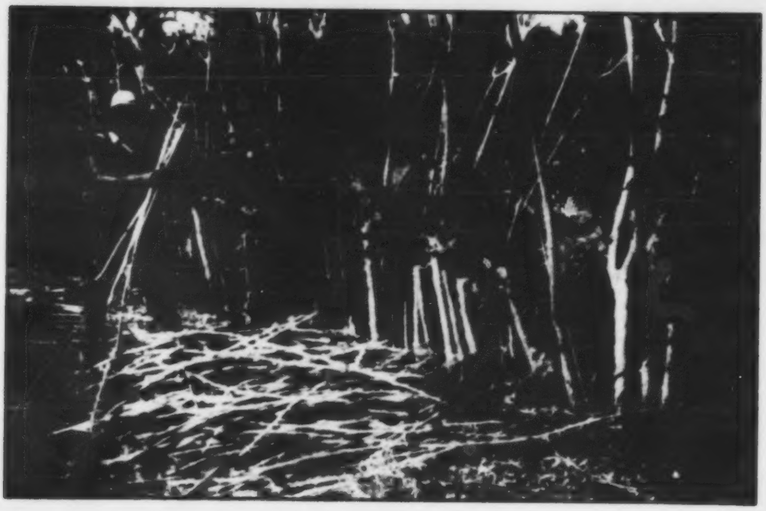

Fig. 1. Farmer harvesting *Gliricidia* and the resulting wood for fuel in the three-strata forage system in Bali.

Cattle

- TSFS cattle gained more weight and had a better feed-conversion ratio than NTFS cattle because of the better feed supply and feed quality.
- TSFS farmers spent less time managing cattle because the feed is always available and the animals are stall-fed close to the plots.
- TSFS land can carry 4 cattle/ha; NTFS land can carry only 2 cattle/ha.
- Forage in the TSFS plot (0.25 ha) can support cattle up to 300 kg; forage in the NTFS plot (0.50 ha) can support a cattle up to 200 kg.

Conservation of the environment

- Soil erosion in TSFS is less than that in NTFS because of the buffering effect of the forage and fodder in the first and third strata.
- TSFS creates a more pleasing environment; the plants and forage in the first, second, and third strata remain green almost all year.

Other farming activity

- Because flowering times for grasses, shrubs, and trees are different, it is possible to have a year-round pollen supply; this encourages bee keeping and honey production.
- Periodically, grass and legume seeds are scattered on the ground; white ants (termites) are also common in forage debris. These become carbohydrate and protein sources for Kampung chicken, which is raised extensively.
- The forage and fodder of the first, second, and third strata become sources of feed and shelter for snails during the wet and dry season; TSFS can encourage "backyard snail production."

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Socioeconomic aspects of the three-strata forage system in Bali

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Abstract *— During the wet season, farm income formed 24.8, 30.2, and 62.1% of total income for the three-strata forage system (TSFS), the non-three-strata forage system (NTFS), and the traditional system (TRDS), respectively. Corresponding values in the dry season were 82.2, 81.2, and 78.1%. The average gross margin per year was 786.50, 504.30, and 351.30 United States dollars (USD), and the contribution of livestock to gross farm income as percentage of total income was 33.8, 28.9, and 35.7% for TSFS, NTFS, and TRDS, respectively. In the wet season, each TSFS plot produced 24.80 USD compared with 20.40 USD for NTFS. In the dry season, each TSFS plot produced 155.90 USD compared with 141.80 USD for NTFS. TSFS plots generated 18.50 USD more than NTFS (74.00 USD/ha) annually.*

Résumé *— Durant la saison humide les revenus de l'exploitation agricole ont formé 24,8, 30,2 et 62,1 % du revenu total du régime à trois espèces fourragères (RTEF), du régime sans trois espèces fourragères (RSTEF) et du régime traditionnel (RT), respectivement. Les chiffres correspondants pour la saison sèche ont été 82,2, 81,2 et 78,1 %. La marge brute moyenne par année a été de 786,50, 504,30 et 351,30 en dollars des É.-U. (USD). Quant à la contribution du bétail au revenu brut de l'exploitation agricole, exprimée en pourcentage du revenu total, elle a été de 33,8, 28,9 et 35,7 % pour le RTEF, le RSTEF et le RT, respectivement. Durant la saison humide, chaque parcelle RTEF a produit 24,80 USD comparativement à 20,40 USD pour la parcelle RSTEF. Durant la saison sèche, chaque parcelle RTEF a produit 155,90 USD en comparaison de 141,80 USD pour la parcelle RSTEF. Les parcelles RTEF ont produit 18,50 USD de plus que les parcelles RSTEF (74 USD/ha) par année.*

Resumen *— Durante la estación de lluvias, la renta de la explotación agrícola constituyó el 24,8, 30,2, y el 62,1 por ciento de la renta total para el sistema de forraje en tres capas (TSFS), el sistema forrajero diferente del anterior (NTFS) y el sistema tradicional (TRDS), respectivamente. Los valores correspondientes en la estación de sequía fueron 82,2 81,2, y 78,1 por ciento. El margen bruto promedio por año fue 786,50, 504,30 y 351,30 dólares estadounidenses (USD), y la contribución de la ganadería a la renta bruta de la explotación agrícola como porcentaje de la renta total fue del 33,8, 28,9 y 35,7 por ciento para el TSFS, NTFS y TRDS, respectivamente. En la estación de lluvias, cada parcela del TSFS produjo 24,80 USD comparado con 20,40 USD para el NTFS. En la estación de sequía, cada parcela del TSFS produjo 155,90 USD comparado con 141,80 USD para NTFS. Anualmente, las parcelas del TSFS produjeron 18,50 USD más que NTFS (74,00 USD/ha).*

Introduction

Most farmers in Bali are traditional smallholders. Their main activity is growing food crops; livestock production is a sideline activity. As a result, the income from livestock is only 29–43% of the net farm income (Putra and Arga 1979). In dryland farming areas, the contribution of livestock to farm income tends to be higher than in wet farming areas.

The concept and development of the three-strata forage system (TSFS) has been described by Nitis et al. (this volume) and its design and methodology by Lana et al. (this volume). A study on economics showed that the net farm incomes of TSFS, non-three-strata forage system (NTFS), and traditional system (TRDS) farmers were about 1 204 000, 888 000, and 355 000 IDR, respectively (Nitis 1986) (in July 1989, 1 700 Indonesian rupiah [IDR] = 1 United States dollar [USD]). It was also found that the contribution of livestock to total farm income was 41.5, 33.8, and 49.9% for TSFS, NTFS, and TRDS farmers, respectively.

As a follow-up, it was proposed to examine in more detail other economic aspects. The objectives of this study were

- to evaluate the farmer's and farm's income during dry and wet seasons for TSFS, NTFS, and TRDS,
- to evaluate the income per experimental plot of TSFS and NTFS farmers' groups during the wet and dry seasons, and
- to compare whole farm income per hectare and income per hectare from the TSFS experimental plots and from NTFS plots. This paper presents the results of this study.

Materials and methods

Farmer sample

Using a prepared questionnaire, researchers interviewed 39 farmers (12 TSFS, 14 NTFS, and 13 TRDS) about their economic activities. A monthly farm survey was also carried out using a simpler questionnaire.

TSFS farmers have their own farm and plots within the farm. NTFS farmers have their own farm but not a three-strata forage system. Traditional farmers (TRDS) have their own farm but neither TSFS nor NTFS plots.

Methods of analysis

Average gross farm income, gross margin, gross margin per hectare, gross margin of the experimental plots (TSFS and NTFS), and cost structure for the three groups of farmers were determined by farm accounting methods. The income flow was divided into two groups: wet and dry seasons.

Results

Farming system

The TSFS project is located in Bukit Pecatu village in Bali. It ranges from the coast (sea level) to a hilly area, 150 m above sea level. The area is 30% flat and 70% undulating. The soil is red-brown mediterranean, with a calcareous limestone base. In this area, farmers make up 80% of the population, with landholdings varying from 0.5 to 2.5 ha. The cash crops most commonly grown are corn, soybean, and cassava, and the main fruit crops are mangoes, sugar apples, and oranges. In 1988, the orange crop was destroyed by citrus vein phloem disease (CVPD). Other perennial crops that have been grown by farmers, especially after the "greening campaign" of the government, are kapok and cashew nut. The local important fibre plant is screw pine (*Pandanus* spp.). It is used in mat making. Firewood is also locally important, contributing to monthly income and providing a source of energy.

The ruminants reared are cattle and goats. Cattle are fed grasses and crop residues during the wet season and shrubs and tree leaves during the dry season. Male cattle are preferred over female cattle. Pigs and poultry are also important in supplementing the farmer's income.

Educational level of farmers

Out of the 245 farmers, 85 were illiterate (34.7%): 23 of these were male and 62 were female. Among males, 17.3% had attended junior high school, 13.5% had attended senior high school, and 2.3% had gone to university. Among women, corresponding values were 8.0, 7.1, and 0% (Table 1). For adult males above 30 years (45.9% of total), 65.6% finished elementary school and 34.4% were illiterate; for women, 85% were illiterate and only 15% finished elementary school. Within the 10–30 year age group, 33.3% of females were uneducated compared with only 7.7% of males.

Land use

The farmers used their land to grow grasses for the cattle and for annual cropping (corn, soybean, and cassava). Sloping land was used for grasses and flat land was used for annual crops. The farmers believe that if they grow annual crops on sloping land, the crop will fail. On the borders of the fields, farmers grew fences dominated by cactus, wild shrubs, and trees. The trees and shrubs supply green feeds for the cattle. For the annual crop, all the farmers practiced simultaneous planting to make the most efficient use of the rainwater supply. They planted the cassava, corn, and soybean within rows. The distance between two rows of cassava and corn was 1 m; for soybean, 25 cm. The distance between a cassava row and the nearest corn row was 50 cm. Soybean was planted between rows of cassava and corn.

The average landholdings were 3.8, 3.7, and 2.3 ha for TSFS, NTFS, and TRDS farmers, respectively. The average grass fields were 2.9, 2.1, and 1.4 ha and annual

Table 1. Education level of the adult members (10 years and above) of the 39 farming families.

	Males				Females			
Level of schooling	TSFS	NTFS	TRDS	% of total	TSFS	NTFS	TRDS	% of total
None	11	6	6	17.3	25	20	17	55.4
Elementary	23	20	23	49.6	12	8	13	29.5
Junior high school	13	8	2	17.3	4	2	3	8.0
Senior high school	10	5	3	13.5	4	4	0	7.1
University	1	2	0	2.3	0	0	0	0.0
Total	58	41	34		45	34	33	

Note: TSFS, three-strata forage system; NTFS, non-three-strata forage system; TRDS, traditional forage system.

Table 2. Farm characteristics.

	TSFS	NTFS	TRDS
Average landholding (ha)	3.8	3.7	2.3
Grassing field (ha)	2.9	2.1	1.4
Annual cropping (ha)	0.9	1.6	0.9
Cropland under ownership (%)	100	100	100
Livestock ownership (head/farm)			
Cattle	9	8	6
Pigs	3	1	1
Goats	1	—	—
Chickens	51	47	25
Gross farm income (USD/year)	1 123.6	785.3	660.5

Note: TSFS, three-strata forage system; NTFS, non-three-strata forage system; TRDS, traditional forage system.

cropping fields were 0.9, 1.6, and 0.9 ha for TSFS, NTFS, and TRDS farmers, respectively (Table 2). All of the 39 farmers, held ownership tenancy.

The most important livestock was cattle (Table 2), mainly used for draft, breeding, and fattening. They were also raised for security (as an investment), as collateral for production loans, and as a form of savings.

Pigs are raised for fattening. The income from rearing pigs is used to provide cash to meet the immediate needs of the household and for the "adat" ceremony. Chickens are also used to provide family income and "adat" ceremony.

Income sources

Farming is the main occupation of the farmers. Limestone quarrying, small-scale trading, harbour and airport labour, construction work, and carpentry are other sources of income for men. Women earn extra income by plaiting mats, waiting on tables, and in small-scale trading, pig raising, and shop keeping.

The average farm income in the wet season for TSFS and NTFS was less than the average nonfarm income (Table 3). For the traditional systems, however, farm income is higher than nonfarm income in the wet season. In the dry season, farm income is always higher than nonfarm income. The gross average incomes in the wet season for TSFS, NTFS, and TRDS were 120.20, 111.10, and 151.00 USD, respectively. Corresponding values for the dry season were 1 329.40, 926.00, and 725.40 USD. The average gross farm income was 823.30 USD/year: 52.50 USD (6.2%) in the wet season and 785.80 USD (93.8%) in the dry season (Table 4).

Average gross farm income was 14.53 USD/ha (24.7×10^3 IDR/ha) in the wet season and 236.06 USD/ha (401.3×10^3 IDR/ha) in the dry season, for a total of 250 USD/ha over the year. The average incomes in wet season were 7.70, 9.00, and 34.53 USD and, in the dry season, 284.47, 202.35, and 188.24 USD, for TSFS, NTFS, and TRDS, respectively (Table 5).

Cash costs and gross margin

Average total farm expenses per year were 529.5×10^3 IDR, of which 98.0% was spent in the wet season (Table 6). This is because most of the farm activities

Table 3. Average gross income (IDR × 10³).[a]

	Wet season			Dry season		
	TSFS	NTFS	TRDS	TSFS	NTFS	TRDS
Farm income						
Cash crop	29.7	34.8	25.2	1 176.9	856.5	653.8
Livestock	—	—	120.0	646.2	386.0	280.7
Manure	7.6	5.6	4.9	11.9	8.1	1.5
Firewood	13.4	16.7	9.4	24.4	27.4	27.2
Total	50.7 (24.8)[b]	57.1 (30.2)	159.5 (62.1)	1 859.4 (82.2)	1 278.0 (81.1)	963.2 (78.1)
Nonfarm income						
Limestone quarrying	93.7	26.7	41.1	158.3	58.5	114.2
Mat plaiting	4.6	3.9	18.3	12.2	34.7	31.4
Small-scale trade	—	86.7	5.0	1.4	133.6	21.1
Carpentry	2.5	—	16.1	4.8	3.5	29.2
Hired labour	9.8	14.2	12.6	10.5	29.5	36.1
Other jobs	42.9	—	3.8	213.3	36.0	37.6
Total	153.5 (75.2)	131.5 (69.8)	96.9 (41.8)	400.5 (17.8)	295.8 (18.9)	270.3 (22.9)
Farmer average	204.2	188.6	256.4	2 259.9	1 573.8	1 233.5
Gross income (USD)[a]	120.2	111.1	151.0	1 329.4	926.0	725.4

Note: TSFS, three-strata forage system; NTFS, non-three-strata forage system; TRDS, traditional forage system.

Source: Nitis et al. (1988b).

[a] In July 1989, 1 700 Indonesian rupiah (IDR) = 1 United States dollar (USD).

[b] Values in parentheses are percentages of the total income.

Table 4. Average gross farm income during the wet and dry seasons (IDR × 10^3/farm).[a]

	Wet season				Dry season			
	TSFS	NTFS	TRDS	All farms	TSFS	NTFS	TRDS	All farms
Cash crops								
Corn	13.5	12.4	11.6	12.5	—	—	—	—
Soybean	—	—	—	—	407.3	434.7	259.8	368.0
Cassava	—	—	—	—	270.1	130.6	19.9	136.6
Other beans	—	—	—	—	27.8	35.4	58.2	40.6
Sugar apple	15.8	22.4	13.6	17.4	—	—	—	—
Coconut	—	—	—	—	20.1	9.2	2.6	10.4
Kapok	—	—	—	—	392.9	233.2	297.6	203.8
Cattle								
Cattle sold	—	—	105.0	35.0	525.9	303.5	226.5	346.2
Pigs								
Pigs sold	—	—	15.0	5.0	83.6	50.5	25.7	36.1
Poultry								
Chickens sold	—	—	—	—	36.7	31.8	28.5	32.2
Others								
Farm yard manure	7.8	5.5	4.7	5.9	11.7	8.2	7.1	8.9
Firewood	13.4	16.7	9.4	13.3	24.4	27.2	21.5	24.4
Average farm income[b]	50.7 (29.8)	57.1 (33.6)	159.5 (93.8)	89.2 (52.5)	1 859.4 (1 093.7)	1 278.0 (751.8)	963.3 (566.7)	1 335.9 (785.8)

Note: TSFS, three-strata forage system; NTFS, non-three-strata forage system; TRDS, traditional forage system.

[a] In July 1989, 1 700 Indonesian rupiah (IDR) = 1 United States dollar (USD).

[b] Values in parentheses are in US dollars.

Table 5. Average gross farm income (IDR × 10^3/ha).[a]

	Wet season				Dry season			
	TSFS	NTFS	TRDS	All farms	TSFS	NTFS	TRDS	All farms
Cash crop	7.6	9.3	10.9	9.1	306.0	230.5	283.5	270.2
Livestock	—	—	52.1	12.1	168.0	103.9	121.0	131.2
Cattle manure and firewood	5.5	5.9	6.1	5.8	9.4	9.5	12.4	10.1
Subtotal (season)[b]	13.1 (7.7)	15.3 (9.0)	58.7 (34.5)	24.7 (14.5)	483.6 (284.5)	344.0 (202.4)	320.0 (188.2)	401.3 (236.1)
Total (both seasons)[b]	496.7 (291.2)	359.3 (211.4)	378.7 (222.8)	426.0 (250.0)				

Note: TSFS, three-strata forage system; NTFS, non-three-strata forage system; TRDS, traditional forage system.

[a] In July 1989, 1 700 Indonesian rupiah (IDR) = 1 United States dollar (USD).

[b] Values in parentheses are in US dollars.

Table 6. Cash costs during the wet and dry seasons (IDR × 10^3/ha).[a]

	Wet season				Dry season			
	TSFS	NTFS	TRDS	All farms	TSFS	NTFS	TRDS	All farms
Cash crops	157.6	106.9	132.5	136.4	—	—	—	—
Seeds (soybean and corn)	32.5	22.1	31.7	30.0	—	—	—	—
Cutting (cassava)	11.1	4.6	7.4	8.9	—	—	—	—
Land preparation	63.9	39.8	51.4	53.6	—	—	—	—
Weeding	50.0	40.0	42.0	43.7	—	—	—	—
Cattle	388.4	345.5	369.2	367.7	11.9	11.2	7.6	10.2
Cattle (2–3 years old)	382.5	340.0	365.5	362.6	—	—	—	—
Cattle shed	2.7	2.4	—	1.7	5.6	4.9	—	3.5
Rope	0.6	0.6	1.3	0.8	1.3	1.3	2.6	1.7
Sickles	0.8	0.8	0.8	0.8	1.6	1.6	1.6	1.6
Medication	0.6	0.6	0.6	0.6	1.3	1.3	1.3	1.3
Baskets	0.9	0.9	0.9	0.9	2.0	2.0	2.0	2.0
Pigs								
Piglets	15.0	14.0	16.0	14.9	—	—	—	—
Total cost (season)	561.0	466.4	517.8	519.2	11.9	11.2	7.6	10.2
Total cost (both seasons)	572.9	477.7	525.5	529.5				

Note: TSFS, three-strata forage system; NTFS, non-three-strata forage system; TRDS, traditional forage system.
Source: Nitis et al. (1988b).

[a] In July 1989, 1 700 Indonesian rupiah (IDR) = 1 United States dollar (USD).

Table 7. Gross margin per lot (IDR × 10^3).[a]

	Wet season		Dry season		Both seasons	
	TSFS	NTFS	TSFS	NTFS	TSFS	NTFS
Corn[b]	3.9	4.1	—	—	3.9	4.1
Soybean	—	—	119.2	144.6	119.2	144.6
Cassava	—	—	79.0	43.4	79.0	43.4
Cattle	28.2	22.9	42.1	34.1	70.3	57.1
Feed						
Corn straw	2.6	5.4	—	—	2.6	5.4
Soybean straw	—	—	7.2	11.2	7.2	11.2
Cassava straw	—	—	5.0	7.6	5.0	7.6
Grasses (cenchrus and panicum)	6.0	—	—	—	6.0	—
Legumes (urochloa, verano, and centrosema)	1.3	—	—	—	1.3	—
Shrubs (gliricidia and leucaena)	—	—	5.0	—	5.0	—
Trees (ficus, lannea, and hibiscus)	—	—	0.3	—	0.3	—
Native grass	—	2.2	—	—	—	2.2
Firewood (gliricidia and leucaena)	—	—	6.9	—	6.9	—
Total[c]	42.0 (24.8)	34.6 (20.4)	264.7 (155.9)	240.9 (141.8)	306.7 (180.4)	275.6 (162.1)

Note: TSFS, three-strata forage system; NTFS, non-three-strata forage system; TRDS, traditional forage system.

Source: Nitis et al. (1988b).

[a] In July 1989, 1 700 Indonesian rupiah (IDR) = 1 United States dollar (USD).

[b] The corn crop failed in 1987, 1988, and the first half of 1989.

[c] Values in parentheses are in US dollars.

Table 8. Time spent on keeping cattle (min/head per year).

Activity	TSFS	NTFS	TRDS
Feed collection	58	61	77
Feeding	19	20	70
Watering	17	18	24
Watching	21	38	60
Total time	115	137	178

Note: TSFS, three-strata forage system; NTFS, non-three-strata forage system; TRDS, traditional forage system.

Source: Nitis et al. (1988a).

are carried out in the wet season. The expenses in the wet season included 26.3% for cash crop and 70.8% for cattle activities.

The average gross margins per year were 1 337 × 10^3, 857 × 10^3, and 597 × 10^3 IDR for TSFS, NTFS, and TRDS, respectively. For all farms, the average gross margin was 918 × 10^3 IDR.

The benefit of TSFS plots

In terms of gross margin per year, the benefit of the TSFS plots was 306.7 × 10^3 IDR (180.40 USD) compared with 275.6 × 10^3 IDR (162.12 USD) for NTFS (Table 7). Average gross margin per hectare per year was 723.20 USD for TSFS and 649.20 USD for NTFS; therefore, each hectare of TSFS produced 74.00 USD more than each hectare of NTFS.

Other benefits of TSFS plots included time saved in feed collection: TSFS plots were always prepared, close by, and had more feeds than NTFS plots. TSFS farmers spend 22 min less per day than NTFS, or 63 min less than traditional farmers, on keeping one cow (Nitis et al. 1988a) (Table 8).

At current prices and given the available technology, the gross margin of the plots is affected by the slope of the land, rainfall distribution, the age of the trees that surround the plots, and the total weight gain of the cattle kept in the plots. Sloping land will produce less cash crops than flat land. Rainfall is unpredictable. Firewood and forage production depend on the age of the trees around the plots. The older the tree, the more firewood and forage will be produced, and the greater the contribution to total income. Cumulative weight of cattle kept in the plots always increases to the maximum. Hence, the gross margin of profits from cattle rearing will also increase.

There are some other unaccountable benefits of TSFS. These include increased land fertility, decreased erosion, rearing honey bees, and support for the government's greening program (Nitis et al. 1988b).

Acknowledgment

The authors thank Wayan Suwindu for data collection.

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Communication aspects and research extension linkages of the three-strata forage system in Bali

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Abstract *— A course on the three-strata forage system was given at Singaraja, regency of Buleleng, Indonesia, from 12 to 14 December 1988. The participants of the course were farmers from Kubutambahan, Sukasada, and Grokgak districts. Three TSFS (three-strata forage system) demonstration plots were built, one plot for each of the districts, by the course participants with the help of the TSFS team. Pretest and post-test data showed that the knowledge scores of the participants were significantly higher (*$P < 0.01$*) after the course (89.1 vs 79.2, 12.5% increase). The attitudes of the farmers attending the course were significantly more positive (*$P < 0.01$*) than nonparticipants.*

Résumé *— Un cours sur le régime à trois espèces fourragères (RTEF) a été donné à Singaraja, dans la régence de Bulelung, Indonésie, du 12 au 14 décembre 1988. Les participants étaient des paysans des districts de Kubutambahan, de Sukasada et de Grokgak. Trois parcelles de démonstration RTEF ont été établies, une pour chaque district, par les participants avec l'aide de l'équipe RTEF. Les données recueillies avant et après le test ont montré que les connaissances des participants étaient sensiblement plus élevées après le cours (*$P < 0{,}01$*) qu'avant (89,1 contre 79,2, soit une augmentation de 12,5 %). L'attitude des paysans participants était beaucoup plus positive (*$P < 0{,}01$*) que celle des paysans n'ayant pas participé au cours.*

Resumen *— Del 12 al 14 de diciembre de 1988, se impartió en Singaraja, territorio de Buleleng, Indonesia, un curso sobre el sistema forrajero en tres capas. Los participantes de dicho curso fueron granjeros provenientes de los distritos de Kubutambahan, Sukasada y Grokgak. Con la ayuda del equipo TSFS, los asistentes al curso hicieron tres parcelas de demostración del TSFS, una para cada uno de los distritos. Los datos previos y posteriores a la prueba demostraron que los participantes obtuvieron calificaciones significativamente más altos (*$P < 0{,}01$*) después del curso (79,2 antes del curso, 89,1 después del curso, para un aumento del 12,5%). Las actitudes de los granjeros asistentes al curso fueron significativamente más positivas (*$P < 0{,}01$*) que las de los que no participaron.*

Introduction

For farmers in the dryland farming area of Bali, cattle feeds are a major problem, especially during the dry season. The problem exists because of inadequate knowledge, a lack of special land for planting, and the fact that the bare land after harvesting the cash crops is not used effectively to prepare livestock feeds (Nitis, Lana, Suarna, Sukanten, Putra, and Arga 1988).

The three-strata forage system (TSFS) experiment on the Bukit Peninsula, southern Bali, began in October 1984. The research indicated that TSFS produced 90% more feed, 71% higher carrying capacity and could handle a higher stocking rate than the non-three-strata forage system (NTFS). This allows TSFS farmers to spend more time in social activities and gain more profit than NTFS farmers (Nitis 1986).

TSFS has been expanded to Nusa Penida and Seraya, eastern Bali, because of the initiatives of the government, FPP (Foster Parent Plan) Bali, and the private sector (Nitis, Lana, Suarna, Sukanten, Putra, Nuraini, and Arga 1988). To date, there are 175 TSFS units (Nitis et al., this volume).

One aspect of the TSFS study that has not yet been carried out is the impact of communication support on the TSFS adoption rate of farmers. Accordingly, TSFS demonstration plots were set up at three districts of the Buleleng regency to study the impact of TSFS communication. The objectives of this study were as follows:

- Examine the knowledge and attitudes of farmers toward TSFS.
- Evaluate the impact of communication support on TSFS adoption by farmers and the way this support diffuses to the farmer's social system.
- Study the pattern of TSFS communication in the three villages studied.

Site selection

The Buleleng regency was chosen because no TSFS program had been undertaken in its dryland farming areas. Three districts in the dryland farming system were chosen as the sites of TSFS introduction. In choosing the research sites, the TSFS team was assisted by the head of the Buleleng Regency Animal Husbandry Service because of his familiarity to the area.

Farmer selection

The TSFS team, together with the head of Buleleng Regency Animal Husbandry Service, asked the assistance and permission of the heads of the villages in which the TSFS program would be launched, to select the farmers for the TSFS training course and to develop the TSFS demonstration plot in their villages. Fourteen farmers (seven farmers, seven immediate relatives) were selected from each of the three districts; these were the "nucleus farmers." The farmers selected for training owned their own land and farm.

The training course

Course activities

A three-stage course was arranged to ensure that the farmers could understand and follow TSFS step by step. The TSFS team also regularly gave advice during the project. The mass media (e.g., radio programs) also served as a vehicle for communication.

The first stage of the training course was carried out from 12 to 14 December 1988. The other two stages of the course will be carried out in February 1989 and July 1989. There were 46 participants at the first stage:

- 14 farmers from Grokgak district,
- 14 farmers from Sukasada district,
- 12 farmers from Kubutambahan district, and
- 6 field extension officers, 2 from each of the three districts.

The distance to each district is 40–60 km. All of the participants stayed in the two hotels in Singaraja, close to the location of the training course.

Before the course began, each participant received the *Three Strata System Management Practical Guidance* brochure, a T-shirt and cap with the TSFS logo, a notebook, and a pencil. On the 1st day, presentations were made on the following topics:

- livestock development policy for Buleleng regency,
- the concept and development of TSFS,
- land preparation and planting the cash crop, and
- planting the grass, legume, shrub, and trees.

There was a discussion after each talk, giving the participants an opportunity to deeply understand each topic.

On the 2nd day, the participants returned to their respective districts, with four TSFS teams for each district. With the help of the TSFS teams, the participants practiced aspects of the topics they were taught the previous day. This "learning by doing" approach will help the participants easily understand TSFS. The following activities were carried out: mapping the land for the TSFS demonstration plot; preparing the land for cash crops, grasses, legumes, shrubs and trees; and planting the shrubs and trees.

Supervised by the TSFS team, the grasses and legumes were planted in Sukasada district on 20 December 1988, and on 10 January 1989 in Grokgak and Kubutambahan districts. The delay occurred while awaiting rainfall to give enough moisture for establishment.

The questionnaire

A questionnaire on various aspects of TSFS was given to each participant. It was intended to assess their knowledge before and after the course. There were 30 questions, each with three possible responses. The score given to the most expected answer was 3; the second-most expected answer was scored 2; the least expected answer was scored 1. The questionnaire was completed with one open question with the maximum score of 10. Therefore, the maximum total score for the questionnaire was 100. Total scores were classified by modifying the formation of frequency distribution of Dajan (1972): 0–36, very low; 37–52, low; 53–68, medium; 69–84, high; 85–100, very high.

An attitudinal questionnaire was given to each respondent in the first survey (14 April 1989). In each district, 15–16 farmers were randomly selected from the village where the demonstration plot was built as a control group. The questionnaire consisted of 28 statements. Each farmer was asked to respond to each statement and to grade this response from 1 to 5: 1, strongly disagree; 2, disagree; 3, neutral; 4, agree; 5, strongly agree.

The attitude score of the respondent toward TSFS is the sum of the scores from all statements. Therefore, the maximum score of the respondent is 140. The total attitude score of each respondent was classified as follows: 0–36%, strongly disagree; 37–52%, disagree; 53–68%, neutral; 69–84%, agree; 85–100%, strongly agree.

The data collected in the first stage has been analyzed descriptively. The statistical analysis has been done for the knowledge and attitude scores of the respondents.

Results

Education level

The average age of the participants was 27.7 years, ranging from 16 to 50 years (Table 1). The level of formal education of the participants was either primary school, secondary school, or high school. All the field extension officers had finished vocational high school. Most of the participants from Grokgak and Sukasada districts had attended or finished primary school; most of the participants from Kubutambahan district had finished high school (Table 2).

Knowledge levels

The pretest average score of the participants was 79.2 (high); average post-test score was 89.1 (very high). Therefore, the course improved knowledge scores by

Table 1. Age of participants.

Age (years)	District			Total
	Grokgak	Sukasada	Kubutambahan	
16–25	11	9	11	31
26–35	5	4	2	11
36–45	0	2	1	3
46–50	0	1	0	1
Total	16	16	14	46

Table 2. The level of formal education of the participants.

Education level	District Grokgak	 Sukasada	 Kubutambahan	Total
Primary school	11	10	1	22
Secondary school	3	3	1	7
High school[a]	2	3	12	17
Total	16	16	14	46

[a] Includes two field extension officers in each district.

Table 3. Pre- and post-test average scores of the participants based on their district.

District	Pretest A	Pretest B	Post-test A	Post-test B	Improvement (%) A	Improvement (%) B
Grokgak	71.1	73.1	81.8	83.6	15.0	14.4
Sukasada	84.5	85.1	91.4	91.8	8.2	7.9
Kubutambahan	79.3	79.5	91.6	92.0	15.5	15.7

Note: A, farmer participants only; B, including the field extension officers.

12.5% (increase varied from 7.1 to 16.7) (Table 3). The results showed that the higher the level of formal education, the higher the pretest score.

Effect of location and status

The pretest scores of the participants from Sukasada district was 85.1 (very high); Grokgak district, 73.1 (high); Kubutambahan district, 79.5 (high). Post-test scores of the participants from Sukasada and Kubutambahan districts were 91.8 and 92.0, respectively (very high); Grokgak district, 83.6 (high). These differences were statistically significant between pretest and post-test scores for all districts ($P < 0.05, P < 0.01$).

Attitudes toward TSFS

The results indicated that the course participants had a more positive attitude toward TSFS than the nonparticipants for all districts (Table 5). The attitudes of the course participants varied from "agree" (Kubutambahan, 78.8%; Grokgak, 80.9%) to "strongly agree" (Sukasada, 87.2%). For nonparticipants, attitudes varied from "disagree" (Grokgak, 50.9%) to "neutral" (Kubutambahan, 57.6%) to "agree" (Sukasada, 73.1%).

Discussion and conclusions

The knowledge scores of the participants were generally high before the course. Farmers read the course material, which they received the night before the course, at their leisure. Competition among participants from different districts had some impact on these knowledge levels. After the course, average knowledge scores increased significantly. Therefore, the objectives of the training course, to improve the knowledge of the participants and extend knowledge on TSFS, were achieved.

Table 4. Pre- and post-test average scores of the participants based on formal education.

Education	Pretest	Post-test	Improvement (%)
Primary school	73.5	85.7	16.6
Secondary school	80.6	86.3	7.1
High school[a]	82.9	94.1	13.5
High school[b]	82.6	93.4	13.1

[a] Including the field extension officers.
[b] Farmer participants only.

Table 5. The attitudes of the respondents toward TSFS.

District	Attitude score[a]		Mean difference	*T* value[b]
Kubutambahan				
Participants	110.3	(78.8)	29.6	2.89
Nonparticipants	80.7	(57.6)		
Sukasada				
Participants	122.1	(87.2)	19.8	4.40
Nonparticipants	102.3	(73.1)		
Grokgak				
Participants	113.3	(80.9)	42.0	4.00
Nonparticipants	71.3	(50.9)		
Three districts				
Participants	115.6		24.6	5.92
Nonparticipants	91.0			

[a] Values in parentheses are percentages.
[b] For all values, $P < 0.01$.

The course participants had a more positive attitude toward TSFS than the nonparticipants, because of their access to information. Among nonparticipants, those from Sukasada district had more favourable attitudes toward TSFS compared with those from Kubutambahan and Grokgak districts. The head of the village in Sukasada district was eager to motivate his farmers to get involved in demonstration plots and attend meetings with the TSFS team. Therefore, Sukasada district farmers received more information and knowledge than the farmers from the other two districts.

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Discussion

The third session of the workshop focused entirely on the Indonesian experience with three-strata forage system (TSFS). Four papers were presented that described the concept and development of this project, the research methodologies used, and some socioeconomic analysis on communication aspects involving the transfer of technologies developed within the project.

The first paper in this session, presented by Dr Nitis, explained the concept of TSFS, emphasizing the fully integrated nature of the project in terms of research, socioeconomic analysis, technology transfer, and the involvement of farmers. The main objective of the project was to improve and compare a complete land-use system involving cash crops, forage, and animal production.

Many constraints in the implementation of the project, which resulted in its slow rate of development, were noted. Problems related to lack of draught tolerance in some forage species, insect pests, and the productivity of grasses in close association with *Gliricidia*. It was also noted that outputs other than cash crops and animal production have been important, including firewood, chickens, honey, and snails.

Several major points of discussion arose from this paper. One concerned the conflict of interest between allowing forage species to flower for honey production and the resulting lower feeding value (particularly *Stylosanthes* spp.). Dr Nitis indicated that seed production is also an important output for forage species and, therefore, the lower feeding values are acceptable. Other issues discussed included the potential problem of snails attacking the cash crops and the problem of measuring sustainability in a system where some trees are not used for up to 3 years after establishment. The first issue, in practice, is not a problem. The second issue was the reason that this project lasted longer than the "normal" IDRC-funded project.

The second paper, presented by Dr Lana, provided details of the experimental design and measurements taken in the forage, crops, and animal production components of TSFS. It was emphasized that the farmers, in groups, were fully involved in most aspects of the project. Information was also supplied on forage conservation, i.e., making hay or silage to provide additional forage during the long dry season (about 8 months). Details were provided on the methods of measuring and selecting forage for animal feeding and management. A simple assessment of erosion was also attempted within the project.

The main points of discussion following this paper concerned with the measurement of crop production in the different systems and the use of animal manure on crops. In both systems, animal manure is combined with grass to make a compost; this compost is then applied to the crop. In the traditional system, manure is collected only from night stalls and, therefore, less is collected than in TSFS. Discussion also centered on the possibility that poor grass growth under *Gliricidia* in the wet season is not only associated with competition for light but also with other factors.

Dr Arga presented the third paper in this session. It described some of the socioeconomic aspects, including farmers' educational background, land use, livestock holdings, income, and sources of income, as well as comparative marginal analyses of the systems. Positive results included 35% increase in the gross margins from TSFS and less time required by farmers to look after their cattle. Additional sources of income other than cash crops and animal sales were also listed.

The discussion following this paper centered around the difficulties in conducting a comprehensive socioeconomic analysis when the outputs and income from various components of the system had to be considered over a much longer period of time than the duration of the project. It was indicated that there was an intention to continue to monitor and evaluate the productivity of the system beyond the life of the project.

The final paper in this session, presented by Mrs Nuraini, dealt with communication aspects, in particular, assessing the value of training courses that have been given to farmers in local villages to familiarize them with the concept of TSFS, and the technologies and methods required to adopt the system.

Three demonstration plots were set up and a 3-day course was given on topics concerned with livestock-development policy, the concept and development of TSFS, land preparation, and the planting of cash crops, grasses, legumes, shrubs, and trees. The training program was assessed using questionnaires given to participants before and after the course. The questionnaires revealed that the farmers' knowledge was already high before the training and was further improved by the course.

Following this presentation, discussion concentrated on whether there had been any follow-up surveys to assess the rate of adoption of the TSFS concept by farmers who attended the course compared with other farmers. It was indicated that, because the training course had been held recently, this had not been done; however, such an activity would be considered for the future. The group also discussed the possibility of monitoring the impact of the project on other farmers in the country. Further discussion concerned effective means of measuring the sustainability of the system, given the long-term output of some of its components, and the changes that may occur in the productivity of different components.

Session IV

Country Case Studies

Availability and use of fodder shrubs and trees in tropical Africa

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Abstract *— Generally, trees occupy a significant niche in the farming systems and overall way of life in tropical Africa. Fodder shrubs and trees (browse) in this region play a significant role both in farming systems, where they are protected as fallow species, and in livestock production. Livestock in this zone depend largely on browse for their dietary protein. Compared with tropical grass, browse is generally richer in protein and minerals. The importance of browse increases with increasing aridity and is generally most essential in the dry seasons, when most other feed resources depreciate in quality and quantity. Browse intake increases total dry matter intake, increases crude protein intake, and improves the digestibility of low-quality forages. The effect of browse feeding on livestock is shown in increased survivability (i.e., lower mortalities, especially over the dry season) and increased productivity. Traditionally, throughout tropical Africa, processing and conservation of tree fodder is uncommon, and cultivation is minimal and insignificant. This paper advocates the need for increased cultivation and integration of fodder trees (especially leguminous ones) into local farming systems through agroforestry. It also stresses the need for increased research support for the efficient cultivation, management, and use of fodder shrubs and trees for improved livestock production.*

Résumé *— En général les arbres occupent un créneau important dans le mode de vie de tout paysan de l'Afrique tropicale. Les arbustes et arbres fourragers, dans cette région, jouent un grand rôle tant dans les systèmes d'exploitation agricole, où ils sont protégés comme espèces de jachère, que dans la production animale. Le bétail en tire une bonne partie de ses protéines alimentaires. Comparativement aux graminées tropicales, ces fourrages sont généralement plus riches en protéines et en minéraux. Ces fourrages deviennent plus importants quand l'aridité augmente et, en saison sèche lorsque presque tous les autres fourrages se font rares et de qualité médiocre, ils deviennent essentiels. La consommation de ces fourrages augmente l'absorption totale de matières sèches et de protéines brutes et rend les fourrages de qualité inférieure plus digestibles. Il est prouvé que ces fourrages augmentent la survie (soit moins de mortalités surtout en saison sèche) et la productivité du bétail. Jusqu'à maintenant en Afrique tropicale la transformation et la conservation des arbres fourragers ont été chose rare et leur culture minime et négligeable. L'auteur affirme qu'il faut accroître la culture et l'intégration des arbres fourragers (particulièrement les arbres légumineux) dans les systèmes d'exploitation agricole locaux par l'entremise de l'agroforesterie. Il souligne aussi le besoin de financer plus de recherches sur la culture, la gestion et l'utilisation efficaces des arbustes et des arbres fourragers afin d'améliorer la production du bétail.*

Resumen *— En general, el papel que desempeñan los árboles en los* *sistemas de explotación agrícola es significativo en todas las formas de vida de Africa tropical. Los arbustos y árboles forrajeros (retoños) de esta región desempeñan un papel importante tanto en los sistemas de explotación agrícola, donde se los protege como especies de barbechos (o tierras sin cultivar), como en la producción ganadera. La ganadería en esta zona depende en gran medida de los retoños para obtener su alimento proteínico. En comparación con los pastos tropicales, el retoo generalmente es más rico en proteínas y minerales. La importancia del retoño aumenta en proporción a la mayor aridez o sequedad, y, por lo general, es más esencial en las épocas de sequía, cuando la mayoría de los otros recursos alimenticios disminuyen su calidad y cantidad. El consumo de retoños aumenta el consumo total de materia seca, incrementa el consumo de proteína en bruto y mejora la digestibilidad de los forrajes de baja calidad. El efecto que tiene en la ganadería la alimentación basada en retoños queda demostrado en la mayor supervivencia (o sea, tasas de mortalidad más bajas, especialmente en la estación de sequía) y el aumento de la productividad. Tradicionalmente, en todo Africa tropical, no es frecuente el procesamiento y conservación de árboles forrajeros y el cultivo es mínimo e insignificante. Este estudio pone de relieve la necesidad de mayor cultivo e integración de los árboles forrajeros (especialmente los leguminosos) en los sistemas locales de explotación agrícola mediante la agroforestación. El estudio enfatiza también la necesidad de apoyar más la investigación para cultivar, explotar y utilizar eficazmente los arbustos y árboles forrajeros, con el fin de mejorar la producción ganadera.*

Introduction

Trees are important for two major purposes. The first, environmental protection (including soil fertility maintenance), is conservation-oriented. Watersheds, windbreaks, erosion barriers, forest reserves, and planted fallows are all strategies of conservation. The second purpose is produce-oriented and demands that trees be exploited. This, therefore, includes the harvest of trees as timber, poles, fuelwood, and fodder. Unfortunately, the balance between conservation and produce-use objectives has favoured the latter at the expense of the former.

In tropical Africa, trees occupy a significant niche in the life of the people. The dominant farming system, shifting cultivation or bush fallow rotation, is based strongly on the conservation and regenerative properties of trees (Nye and Greenland 1960; Ruthenberg 1980). This system is now under pressure from the increasing human population, resulting in a shortening of fallow periods and rendering the system inefficient for the regeneration of soil fertility. There is, as a result, an ever-increasing demand for fresh forest land for clearing and cultivation; this has made shifting cultivation a major factor in deforestation.

Use as fodder has also contributed to tree depletion. The importance of browse is universal throughout the tropics, where it serves as a major feed resource, especially in the drier regions and during dry seasons. During these periods, grasses, which are the major feed resource for livestock, dry up and deteriorate both in quality and productivity. De Leeuw and Brinckman (1974), for example, reported that the crude protein content of principal grasses in the Sahel is about 6% from May to mid-July and as low as 2% for most of the dry season. Dry mature grasses have been reported to have little or no digestible protein, practically no carotene, and a low level of phosphorus (Table 1). Ruminants cannot meet their maintenance needs on dry grass alone. Compared with tropical grasses, browse is generally richer in protein and minerals, especially in the dry season

Table 1. Comparison of feed value of dry grass and browse during the dry season.

	Net energy (MJ/kg DM)[a]	Digestible protein (g/kg DM)	P (g/kg DM)	Ca (g/kg DM)	Carotene (mg/kg)
Dry grass straw	2.5–3.4	≤1	≤1	1.5–3.0	≤1
Browse	1.7–2.9	50–300	1.5–2.5	2.5–20.0	50–800
Maintenance needs	2.9	50	1.3	2.5	1.5

Source: Le Houérou (1978).

[a] DM, dry matter.

(Mohamed-Saleem et al. 1979; Adegbola 1985) and contains twice the amount of energy in dry grass (Le Houérou 1980).

Data assembled by Le Houérou (1980) on the nutritive value of browse from West and Central Africa suggest that, potentially, most browse species are able to supply the energy requirements for maintenance and growth of ruminants. The validity of this suggestion for different ruminant livestock species, however, depends on their preference for, and voluntary intake of, browse. The significance and extent of their contribution, however, varies across ecological zones, becoming greater in more arid regions (Le Houérou 1978; Adegbola 1982), where they play a more significant carry-over role in ensuring survival and sustainability of livestock during the dry season.

This paper analyzes the role of shrubs and trees as a feed resource for livestock in tropical Africa. Discussion focuses on the major agroecological zones in sub-Saharan Africa. Specific reference is made to Nigeria because of the familiarity with conditions in that country. Only ruminant animals (cattle, sheep, and goats) are considered.

Agroecological zones

Excluding deserts, there are five major agroecological zones (AEZs) in tropical Africa: humid, subhumid, semi-arid, arid, and montane (highlands) (Fig. 1). The humid zone covers 4.1×10^6 km^2 and receives over 1 500 mm rainfall, with a growing season of more than 270 days (ILCA 1987). The subhumid zone occupies 21% of tropical Africa, some 4.8×10^6 km^2, and has an average annual rainfall of 900–1 500 mm and a growing period of 180–270 days (ILCA 1983). In the arid and semi-arid zones, annual rainfall varies from 100 mm to 1 000 mm and plant-growing time is less than 180 days. The semi-arid zone falls between the 600 and 1 000 mm annual rainfall isohyets; the arid zone includes all land receiving less than 600 mm annual rainfall (Ahmed 1986).

The vegetation across these various ecozones is closely related to the climate (especially rainfall) and soil. It ranges from moist evergreen forests in the humid zone, Guinea savannah and Sudan savannah in the subhumid and semi-arid zones,

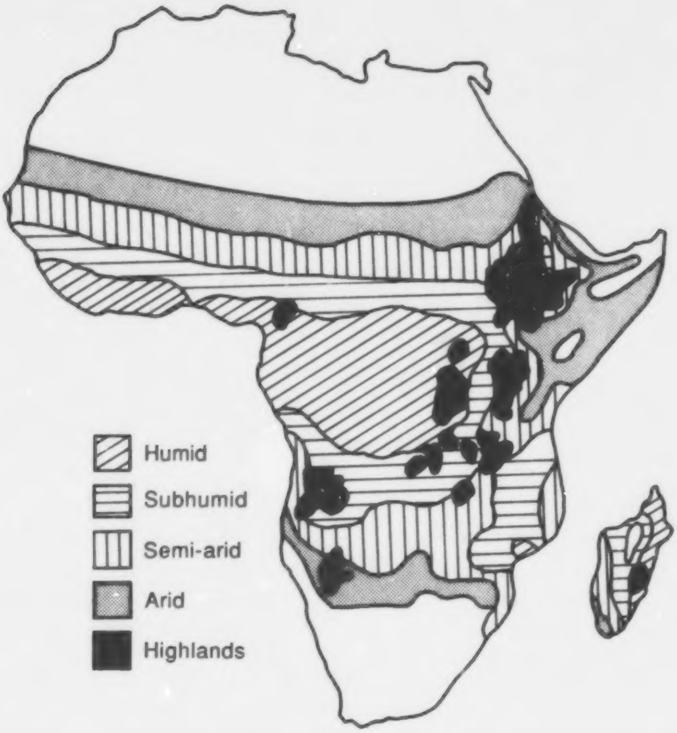

Fig. 1. Ecological zones of sub-Saharan Africa

to steppe with few scattered trees or bushes or steppe with herbs or grasses in the Sahel region (Adegbola 1982).

Importance and availability of shrubs and fodder trees

In the various AEZs, the importance and availability of fodder shrubs and trees are influenced by many factors. The most important are

- the natural distribution of trees with the zones,
- the distribution, type, and importance of livestock, and their integration and role within the farming system, and
- the availability of alternative sources of fodder (other than from trees) for livestock in the zone.

In the humid zone, trees are the dominant natural vegetation and they constitute the major component of the forests. This region, therefore, has the highest density of trees, which decreases toward the arid regions. The importance and significance of browse across agroecological zones, however, does not follow this pattern; other

Table 2. Ruminant livestock population by species and ecological zone in tropical Africa, 1979.

Ecological zone	Cattle (1 000 head)	Sheep (1 000 head)	Goats (1 000 head)	Ruminants[a] (1 000 TLU)
Arid	31 462	37 063	48 287	41 697
	(21.3)[b]	(35.7)	(38.6)	(30.4)
Semi-arid	45 454	23 071	33 215	37 446
	(30.8)	(22.2)	(26.5)	(27.3)
Subhumid	32 758	14 153	20 266	26 370
	(22.2)	(13.6)	(16.2)	(19.2)
Humid	8 814	8 177	11 586	8 148
	(6.0)	(7.9)	(9.2)	(5.9)
Highlands	29 022	21 401	11 933	23 646
	(19.7)	(20.6)	(9.5)	(17.2)
Total	147 510	103 865	125 287	137 308

Source: Jahnke (1982).

[a] Including camels; TLU, tropical livestock unit.

[b] Values in parentheses represent population as a percent of the total.

considerations, such as animal populations and their importance within farming systems are involved. Table 2 gives the distribution of ruminants by ecological zones. The trend is opposite to that observed for tree dominance and density. The density and importance of livestock is highest in the arid and semi-arid regions and decreases toward the humid zone. Thus, the demand for browse and other feeds is higher in the drier areas than it is in the humid regions.

The length of the dry season across the various zones also influences the degree of dependence on browse. The longer and more intense the dry season, the longer the period of grass scarcity during the year, and the more valuable the browse. In the Sahel region of West Africa, for example, the dry season may last as long as 8 months and grass is available for only 3 or 4 months in a year (Adegbola 1982). Browse is, therefore, a critical feed element and plays an essential role in animal production systems.

The availability and use of crop residue is another factor that influences the degree and dependence on browse. Crop-residue availability is influenced by the type of crops grown, the length and reliability of the cropping season, and the crop–livestock system. In the humid zone, little use is made of crop residues for livestock, and, where supplementary feeding is required, shrubs and fodder trees are used. In the subhumid and semi-arid regions, crop residues play a major role in the feeding of livestock during the early dry season (van Raay and de Leeuw 1974). Animals are allowed on cropping lands to graze the residue, enriching the soil in the process through manure droppings. Toward the end of the dry season, when crop residues are used up and grass is at its worst, in quantity and quality, browse receives the most attention from sheep, goats, and cattle.

Major fodder shrub and tree species

Several authors have described tree species used to supply animal feeds to different categories of livestock in the AEZs of Africa. Detailed chemical analyses of these fodders have also been done (Dougall et al. 1964; Roose-Innes and Mabey

Fig. 2. Goats browsing on *Acacia* trees in semi-arid Africa, where grass and herb vegetation is almost totally absent.

1964; Le Houérou 1978). Within Nigeria, this subject has been studied by Mohamed-Saleem et al. (1979), Carew et al. (1980), Mecha and Adegbola (1980), Adegbola (1982), Agishi (1985), and others. The information on major browse shrubs and trees across the various AEZs of Africa refers mainly to West Africa.

Agishi (1985) classified fodder trees and shrubs in Nigerian rangelands into two groups: nonleguminous and leguminous. About 40 families of nonleguminous shrubs and trees were said to be forage species. Legume trees also constitute a major presence in the Nigerian rangelands; about 143 legume genera are represented (Agishi 1984). The subfamily Mimosaceae is the most important source of browse, accounting for 55% compared with 27.5 and 17.5% for Papillionaceae and Caesalpinaceae, respectively. The acacias are the most important browse species in the Sudan zone (Pellew 1980; Toutain 1980), both by number and by density, but they are poorly represented in the less arid regions south of this zone. Many important legume browse species have a wide distribution across zones. *Afzelia africana*, *Daniella oliveri*, and *Pterocarpus erinaceus*, for example, are found in all AEZs but the montane (Agishi 1985).

According to Mohamed-Saleem et al. (1979), the heavily browsed fodder shrubs and trees in the Sudan savannah include *Acacia siberiana*, *Afzelia africana*, *Grawie mollis*, *Khaya senegalensis*, *Pterocarpus erinaceus*, and *Strychnos spinosa* (Fig. 2). Most of them are also available in the Guinea savannah. Audru (1980) listed some of the palatable species of this zone as *Cussonia barterii*, *Daniella oliveri*, *Ficus thonningii*, *Bridelia* spp., and *Albizzia lebbeck*. De Leeuw (1979) included *Dichrostachys cinerea*, *Piliostigma thonningii*, and *Parkia clappertoniana* as browse species relished by livestock in the savannah.

Some of the most commonly selected browse for sheep and goats in the humid forest and derived savannah zones are *Ficus exasperata*, *Newbouldia laevis*, *Aspilia africana*, *Spondias mombin*, and *Cyclicodiscus gabunensis* (Carew et al. 1980).

Mecha and Adegbola (1980) included *Albizzia ferrunginea*, *Ficus elastycoides*, *Baphia nitida*, *Cajanus cajan*, and *Leucaena leucocephala*. *Gliricidia sepium*, although widespread, is known more as a fencing and shade tree than as a fodder tree.

In the acid soil (ultisol) and high rainfall areas of the humid zone, introduced legume tree species such as *Leucaena* and *Gliricidia* have shown poor growth and poor productivity. The most widely used indigenous species in the acid soil region of southeast Nigeria include *Acioa barterii*, *Dialium guinensis*, *Anthonata* spp., *Baphia nitida*, *Harungana madagascariensis*, and *Alchornea cordifolia* (ILCA 1987; Wahua and Oji 1987).

Use patterns of shrubs and tree fodders

The degree and pattern of use of shrubs and tree fodders is influenced by the dominant livestock species and farming systems. In the humid zone, small ruminants are the dominant ruminant livestock species and their production is generally extensive with little or no management inputs. The major farming activity is tree crop (cocoa, oil palm, and kola) cultivation. Farming systems are based on shifting cultivation (Ruthenberg 1980) and land is either under cropping or in fallow.

Small ruminants in the humid zone are managed extensively or in smallholder confinement systems. The former occurs in southwest Nigeria and sheep and goats obtain their major feed requirements by scavenging around households, and by grazing and browsing along roadsides and in fallow lands (Atta-Krah and Reynolds 1989). In areas with high population densities (e.g., southeast Nigeria), cultivation is intensive and compound farming is practiced. In such areas, livestock is usually confined (at least during the cropping season). Cut and carry of fodder is therefore practiced. Browse from fallow lands constitutes the major component of feed offered and these trees are well valued and protected even on cropping land. However, over-exploitation and lack of management are threatening the continued availability of this highly valued feed resource.

In the subhumid zone, livestock are more important and better integrated into the farming system than in the humid zone. According to Mohamed-Saleem et al. (1986), crop–livestock production systems in the subhumid zone range from intensive cropping with no livestock kept (though residue is grazed by pastoralists' cattle) through settled agropastoralism to settled pastoralism, with little or no cropping. In all these systems, crop residue is used as livestock feed during the dry season. Cattle are herded on natural pasture and communal grazing lands throughout the year, but especially in the cropping season and in the late dry season. Small ruminants are restricted during the cropping season and some cut-and-carry feeding is practiced, with browse such as *Afzelia africana*, *Daniella oliveri*, and *Ficus thonningii* frequently used. Browse is also frequently lopped by herders to provide either fruit or leaves for grazing cattle and sheep (Mohamed-Saleem et al. 1979; Milligan and Sule 1982). In recent decades, the human population has increased in the subhumid zone and cropping has encroached on grazing land. This has resulted in declining availability of trees, grasses, and other herbs used for animals.

In the arid and semi-arid regions, pastoralism is the dominant system, with livestock (especially cattle and, to a lesser extent, sheep) being moved from place to place in search of green pasture. Thus, in the dry seasons, the general movement is toward the less arid south. Such migration could go as far south as the Guinea and derived savannah zones, where trees, shrubs, and grass vegetation, as well as crop residues, are in relative abundance. Goats and sheep are not usually part of this transhumance. They are left, sometimes with herders, to roam the rangeland and grazing reserves and survive on whatever is available in the range. It is during this period that the greatest damage is done to browse, as grazing is unmanaged and excessive. All three classes of ruminant animals are represented in this region, but the high population of goats (see Table 2) is especially significant because of their preference for browse.

Most farmers are conscious of the value of browse trees and the need to conserve them. In most situations, these fodder shrubs and trees constitute the last trace of vegetation before the land is completely depleted. Vast areas of land in this critical state exist in all the arid and semi-arid countries. It is in these zones that one actually sees the process of deforestation leading directly to desertification and the role therein played by livestock and fuelwood gathering and harvesting (Atta-Krah and Okali 1986).

Cultivating and processing shrubs and tree fodders

There is little or no direct forage cultivation in traditional farming systems in tropical Africa. This is due to many factors, including the following:

- the subsistence nature of livestock production in some zones (e.g., small ruminants in the humid zone), which generally precludes activities that involve cost in terms of labour, land, or other resources;
- the extensive system of livestock management in the major livestock areas, which is based on pastoralism; and
- the land factor (in several parts of the tropics land tenure and ownership patterns do not favour individual pasture production; in many instances, the owners of animals do not own land that could be used for forage production).

Processing and preservation of tree fodders on any organized scale is largely unknown and is not practiced to any appreciable extent in any AEZ in tropical Africa. This is a reflection of the lack of management in the use of tree fodders and may reflect the labour constraints for such activities. One exception is the case in Malawi, where *Leucaena* is produced in smallholdings in villages and the foliage is sun dried and either fed as a winter supplement or sold as a cash crop. The dry *Leucaena* leaves are sold to local millers for incorporation in layers diets as a source of carotenoid for yolk pigmentation (Savory et al. 1980). Tree fodder is commonly browsed directly from the tree or is produced by lopping. Tree fodders are also offered fresh in cut-and-carry feeding systems. Some tree fodders, like *Gliricidia*, may be wilted to increase intake.

Proper management of fodder trees can result in increased feed availability for livestock, especially in the dry seasons. Research carried out at the International Livestock Centre for Africa (ILCA) on *Leucaena* and *Gliricidia* in alley farming

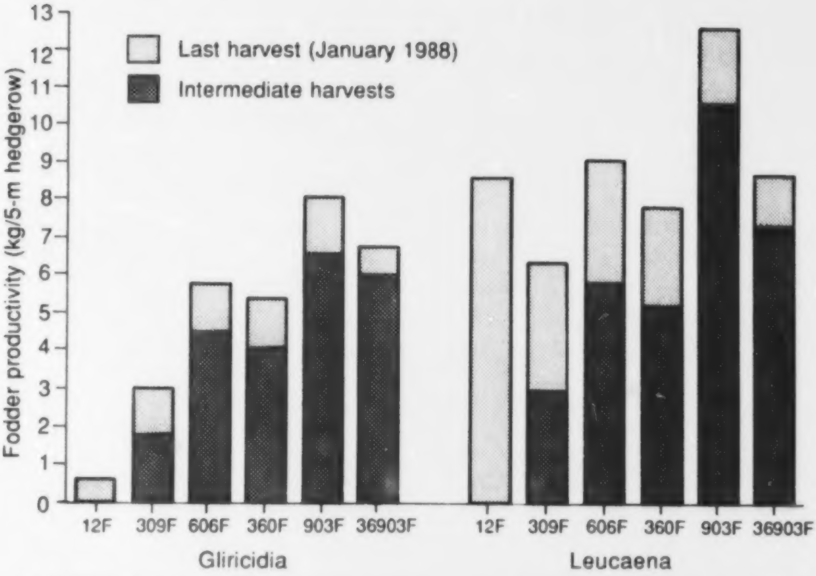

Fig. 3. Effect of pruning management on fodder productivity of tree hedgerows in alley farming fallows. Treatments: 12F, 12 months (Jan.–Jan.) continuous regrowth, single harvest, Jan. 1989; 3D9F, 3 months intermediate harvest (March), 9 months regrowth at final harvest, Jan. 1989; 6D6F, intermediate harvest at 6 months (June), 6 months regrowth at final harvest; 36D6F, intermediate harvests at 3 and 6 months, 6 months regrowth at final harvest; 9D3F, intermediate harvest at 9 months (Sept.), 3 months regrowth at final harvest; 369D3f, intermediate harvests at 3, 6, and 9 months, 3 months regrowth at final harvest (source: Atta-Krah, unpublished).

hedgerows showed significant differences in overall productivity of forage in response to different pruning and management schedules. Foliage harvested before the dry season was conserved by sun drying and storage in sacks for use in the dry season, in addition to foliage retained on the trees (Fig. 3). Simple processing techniques such as sun drying could be used to preserve tree fodders for critical periods such as the dry season (Savory et al. 1980). Some research is required on the major shrub species to determine the effect on feed quality and assess the economics of such systems.

Fodder trees in agroforestry

Most fodder shrubs and trees have many functions. They provide fodder, firewood, poles for building and fencing, live fence, fibre, fruits, spices, fats, medicines, dyes, and tannins (McKell 1980; Wickens 1980; Adegbola 1985). Most of these uses are exploitative and compete, either in the short or long term, with the supply of fodders by the trees. For example, Wilson (1980) reports that 90% of all the wood burned in the Niono area in the Sahel region of Mali is from *Pterocarpus lucens*, which Le Houérou (1979) described as one of the most palatable and nutritious browse species in the region. Some other uses, such as for live fencing, are complementary, as they encourage cultivation of the species and increase the availability of feeds.

Of the various other uses to which fodder trees are put, perhaps the most significant is that dealing with soil fertility maintenance, as it raises the chances of cultivation of fodder trees in production systems. Leguminous fodder trees such as *Gliricidia sepium*, *Parkia clapertoniana*, *Leucaena leucocephala*, and *Acacia albida* have an even better potential in this respect. Traditional farmers have been known to protect and encourage the growth of useful trees on their farmland during both cropping years and fallows. Obi and Tuley (1973) reported several browse tree species as dominating 5- to 10-year fallows in southeast Nigeria. These included *Alchornea cordifolia*, *Acioa barterii*, *Anthonata macrophylla*, *Harungana madagascariensis*, and *Cnestis feruginea*. Such multipurpose trees are commonly protected during cropping years to ensure their regeneration in the next fallow period. During the cropping period, they are managed and put to a variety of uses including fodder and human food.

The traditional tree intercropping (agroforestry) system with *Parkia* spp. and the shea butter tree (*Butyrospermum paradoxum*) in the Guinea and Sudan savannahs, and *Acacia albida* in the drier parts of the African tropics (Sahel region), is an indication of this awareness (Boudet and Toutain 1980; Wickens 1980). Of these examples, only *Acacia albida* is clearly agropastoral in character; both *Parkia* and *Butyrospermum* are probably kept more for their human food use than as fodder. All three examples, however, show the integration of fodder trees into cropping systems, for soil fertility improvement and other products. Crop yields under *A. albida* have been reported to be 56% higher than yields in areas without the tree (Poschen 1986). Felker (1978) also reported that in the infertile sandy soils of the Senegalese groundnut basin, crop yields of groundnut and millet increased from 500 to 900 kg/ha when grown under *A. albida*. Similar results have been reported from India with *Prosopis cineraria* (Mann and Sharnkarnarayan 1980; Mann and Saxena 1981). Both trees are highly preferred fodder species and their attraction to livestock is complementary to their role in maintaining soil fertility, as browsing animals help enrich the soil through their droppings.

Leguminous fodder trees in rangelands have also been observed to influence the productivity of grass growing under them. This is the case in the Sahel of West Africa, where productivity of *Pennesitum pedicellatum* is about twice under the trees than it is in the open (Bille 1978). Also, the grass under the trees dries out 3–6 weeks later and photosynthetic efficiency was 1.4% under shade and 0.3% in the open. Le Houérou (1978) made similar observations in Botswana on *Panicum maximum*. Potential evapotranspiration was reduced by 50–70% under shade and the grass remained green 6 weeks longer into the dry season. A number of agroforestry technologies have been proposed for the development of fodder shrub and tree cultivation within smallholder farming systems (Atta-Krah and Reynolds 1989). These include alley farming, alley grazing, and intensive feed (fodder) gardens.

Alley farming

Alley farming involves the planting of leguminous or other soil-improving fodder trees in rows within arable crop farms. The trees are managed to provide

Table 3. Leaf biomass, nitrogen, and crude protein yield of alley farming tree species.

Species	Total annual leaf biomass yield[a] (t DM/ha)	Annual nitrogen yield[a] (kg/ha)	Crude protein[b] (%)
Acioa barterii	3.0	40.5	8.2
Alchornea cordifolia	4.0	84.8	12.0
Gliricidia sepium	5.5	169.1	20.0
Leucaena leucocephala	7.4	246.5	21.25

[a] Source: B.T. Kang (unpublished, cited in Kang and Reynolds 1986).
[b] Crude protein (CP) content estimated as N × 6.25.

mulch on a continuous basis to maintain soil fertility and to provide fodder at critical periods for livestock. The concept is based on the alley cropping system (Kang et al. 1981) developed at the International Institute of Tropical Agriculture (IITA) in which legume trees are integrated into cropping fields to maintain soil fertility and promote continuous cropping. Food crops are planted in the 4-m alleys between established tree rows. Tree pruning management during the cropping period should prevent excessive shading of arable crops growing within alleys. The nitrogen-rich prunings (foliage and twigs) are used as green manure or as mulch to improve soil fertility and enhance crop production. When fodder tree species are used in alley farming, some of the prunings (foliage) could also be fed to livestock. Leguminous, nitrogen-fixing fodder trees, therefore, have a special advantage in these systems, although nonlegumes can also be used. Information on the establishment and management of alley farms can be found in Kang et al. (1984) and Reynolds et al. (1988).

The foliage productivity and foliar N content of alley farming tree species may be seen as significant elements both in soil fertility maintenance and in feed production. Annual foliage productivity of *Leucaena* and *Gliricidia* under alley farming management is 5–8 t dry matter (DM)/ha, with four to six cuttings per year (Kang et al. 1981; Atta-Krah et al. 1986). Table 3 shows foliage DM, nitrogen yield, and crude protein contents of four tree species (two legumes and two nonlegumes) used in alley farming. Both biomass productivity and N content of the legume trees were observed to be higher than for the nonlegumes.

Alley grazing

Alley grazing is simply the grazing of alley farms by livestock during periods when no crop is carried on the land. This system allows direct integration of livestock within alley farming. The grazing period could be during the dry season, at which time the animals may graze on crop residues, natural weed growth, and tree regrowth. It could also be through integration of specific grazed fallow periods in rotation with cropping, within the alley farming system (Atta-Krah et al. 1986).

Even though effects on soil, crops, and trees are all positive following a grazed fallow, animal management within the system poses a number of practical problems, raising doubts as to its practicality and suitability for smallholder farmers (L. Reynolds, personal communication). Some of the problem issues are the

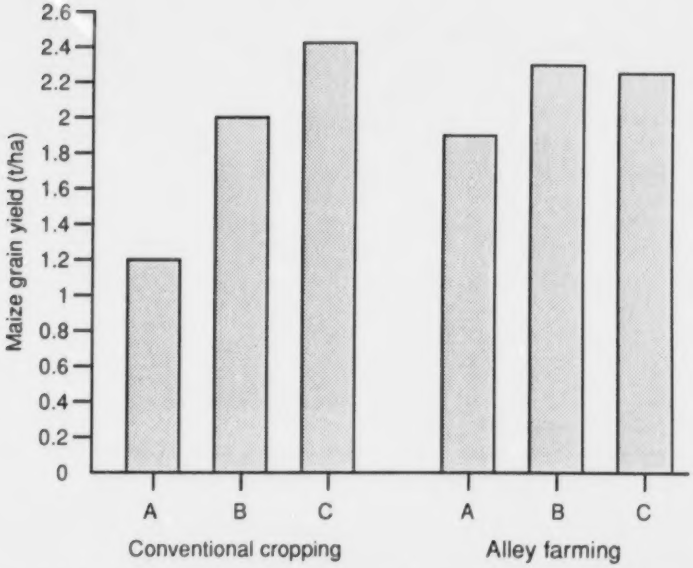

Fig. 4. Effect of 2-year fallow with and without livestock on first-season maize yields under conventional cropping and alley farming with gliricidia: A, continuous cropping; B, cropping after 2 years of ordinary fallow; C, cropping after 2 years of grazed fallow.

requirement for fencing, theft of animals left grazing in fields, and over-grazing and debarking of trees by animals. Debarking is more serious with goats than with sheep and can result in loss of trees and lower productivity of prunings when these fallow plots revert to cropping. This could reduce the expected gain in crop yield in postfallow cropping, compared with yield from an alley farm that has benefited from an ordinary fallow without livestock. Such observations have been made in a trial with *Gliricidia sepium* with integration of a 2-year grazed and ordinary (ungrazed) fallow (Fig. 4).

Intensive feed gardens

The intensive feed garden (IFG) is a system in which fodder trees are cultivated either in sole stands or in combinations with grasses. They are especially suitable for farmers who show some intensification in their livestock production and are prepared to invest in pasture production, even if only on a very small scale.

With tree–grass systems, tree hedgerows may be established 4 m apart, with four rows of grasses sown in between. Tree hedgerows may also be established 2.5 m apart with two rows of grasses. This latter arrangement has a high density of trees, and therefore, a higher protein yield; however, it requires more management attention. Using leucaena and gliricidia mixed with *Panicum maximum* in such gardens, a productivity of over 20 t DM/ha of mixed tree–grass fodder is available from both designs under humid zone conditions (Atta-Krah and Reynolds 1989).

With tree-only plots, productivity is dependent on the interrow spacing of the hedgerow and the cutting frequency. Research at ILCA has shown that, of the two factors, cutting frequency has a greater effect on tree productivity. Increasing the regrowth cycle (period between cuttings) from 6 to 12 weeks leads to fewer harvests per year, but gives a greater total yield of fodder. Also, increasing interrow spacing from 0.5 through to 2.0 m results in decreasing yields per unit area. For 3 consecutive years, the highest yield of fodder has been obtained from the combination of 0.5-m interrow spacing with a regrowth cycle of 12 weeks (ILCA 1987, 1988). An annual fodder yield of over 30 t DM/ha has been obtained from this combination in the 3 years of cultivation.

Effect of browse intake on livestock

The fact that browse is available during periods of stress and scarcity is important. Some livestock species have a preferred taste for browse, and this adds to their importance. Species such as cattle are primarily grazers; others such as goats and camels are mainly browsers; sheep are in-between. A. Blanchemain (unpublished; FAO, Rome, 1964) showed, for instance, that high-performance goats producing 1 000 kg of milk in 300 days can still consume up to 30% of their diet in browse.

Survivability on browse has been clearly and satisfactorily explained by Sarson and Salmon (1978), who worked out the relationship between maintenance needs of cattle, sheep, and goats and possibilities of ingestion with respect to quality per 100 kg live weight. This analysis showed that browse (nutritional value of which varies from 0.25 to 0.40 feed units (FU)/kg DM) alone cannot ensure the maintenance requirements of cattle (0.65 FU/kg DM). It can, however, ensure maintenance of sheep (0.35 FU/kg DM), but does not allow production. With goats, maintenance and production may be provided on a pure browse diet (0.19 FU/kg DM). This explains why only goats, camels, and some wild herbivores can survive on depleted rangelands, where browse constitutes most of the feed. It also explains why goats and camels are less affected by catastrophic droughts in the Sahel of Africa, compared with sheep and cattle (Le Houérou 1978).

Another reason for the importance of browse is its effect on intake. Often, when the quality of feed drops, livestock respond by taking in less. For example, consumption of *Andropogon gayanus* by heifers decreased from 76 to 47 g/kg metabolic body weight when CP of the hay decreased from 5.35 to 2.35% (Zemmelink et al. 1972). Research conducted at the Humid Zone Programme of ILCA with sheep and goats receiving ad libitum grass (*Panicum maximum*) and different rates of mixed leucaena–gliricidia supplements, showed that increasing levels of browse legume supplementation led to a decrease in intake of *Panicum*, an increased intake of the legume browse fodder, reflecting amounts offered, and an overall increase in total DM intake (Fig. 5). This situation was observed both for adult animals and for freshly weaned lambs (Reynolds and Adediran 1988). Similar results have been reported by other workers (Ademosun et al. 1985; Ademosun et al. 1988).

Because of the generally high protein content of browse, its intake affects the digestibility of overall feed intake by livestock. Based on established relationships, it has been estimated that digestibility of CP tends to approach zero below 3.7%

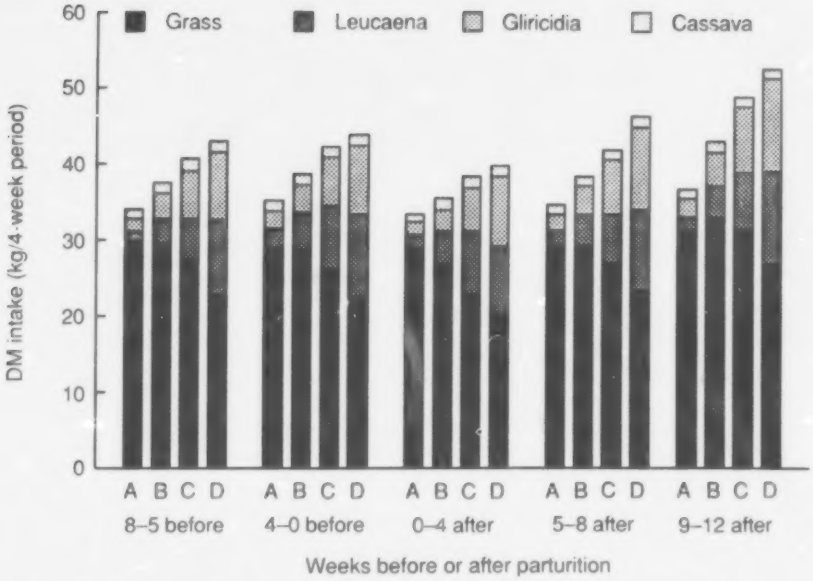

Fig. 5. Dry matter (DM) intake of adult sheep offered different levels of supplementary browse (g/day): A, 550; B, 1 100; C, 2 200; D, 3 300 (source: Reynolds and Adediran 1988).

(Milford and Minson 1966). Generally, if the level of crude protein in the diet drops below 6%, as happens with grass during the dry season, rumen microbes are unable to make enough protein to maintain their rate of reproduction and growth. This leads to a drop in the number of microbes in the rumen, slowing the rate of digestion of food and reducing fresh intake (Reynolds and Adediran 1988).

Ademosun et al. (1988) showed that supplementation of grass diets with leucaena and gliricidia not only results in increased DM intake but also improves digestibility and hence the total intake of digestible dry matter (DDM) (Table 4). Another study by the same workers, in which gliricidia and leucaena were fed at 100%, 75:25%, and 50:50%, revealed that inclusion of leucaena into a sole gliricidia diet clearly improved DDM intake (42 vs 37 $g/kg^{0.75}$ per day).

The ultimate effect of supplementation with tree fodder is increased survivability and productivity of livestock. For example, Reynolds and Adediran (1988) showed that supplementation of a grass and cassava peel basal diet with a mixed leucaena–gliricidia feed resulted in significant increases in both growth rate of lambs and their survival to 24 weeks (Table 5). Survival rates of offspring and their growth rates increased with the level of supplementation. In Malawi, dried leucaena leaf meal, as a dietary supplement to maize bran and maize stover, allowed stall fed steers to gain 1.2 kg/head per day (Thomas and Addy 1977). Supplementing a basal diet of *Panicum* grass with leucaena–gliricidia was also reported to reduce the interval between parturitions (Reynolds and Adeoye 1989).

Productivity index from varying levels of mixed leucaena–gliricidia browse offered to adult females during the final 8 weeks of pregnancy through to weaning at 12 weeks postpartum showed a positive effect to supplementation (Reynolds and

Table 4. Some results of feeding trials carried out by the University of Ife Goat Research Project.

Feed	Daily offer (g/kg$^{0.75}$)	Daily intake (g/kg$^{0.75}$)	Digestibility (%)	Daily DDMI[a] (g/kg$^{0.75}$)
P. maximum (well fertilized, 6 weeks)	75.0	54.9±2.2	75.8±2.6	40.6±2.5
P. maximum (hay)	77.1	43.1±6.4	45.0±6.1	19.5±4.1
	74.9	37.2±2.5	55.1±2.9	37.9±3.1
	73.4	36.8±5.1	47.7±3.1	32.6±2.3
C. nlemfluensis (hay)	87.5	40.6	43.2	17.5
	131.5	39.9	46.6	18.5
G. sepium	31.9	31.9±0.2	—	—
L. leucocephala	31.6	31.6±1.2	—	—

Source: Ademosun et al. (1988).

[a] DDMI, digestible dry matter intake.

Table 5. The effects of supplementary leucaena and gliricidia browse on the growth and survival rates of small ruminants, Ibadan, Nigerian humid zone, 1986/87.

Species	Browse intake (g DM/day)		Growth rate (g/day) to:		Survival to 24 weeks
	Dam[a]	Offspring[b]	weaning[c]	24 weeks	
Goats	143	39	17.4	14.0	0.36
	254	83	28.7	20.1	0.46
	554	160	25.9	20.9	0.82
	719	246	31.9	28.3	0.94
Sheep	0	0	39.0	25.4	0.50
	120	34	46.7	30.7	0.62
	239	77	57.2	34.0	0.70
	441	136	66.3	44.5	0.89
	741	250	84.0	50.3	1.00

Source: ILCA (1988).

[a] During the final 2 months of pregnancy up to weaning.

[b] From weaning to 24 weeks.

[c] Weaning at 12 weeks for lambs and 16 weeks for kids.

Adediran 1988). Productivity index, measured as kilograms of lamb weaned per ewe per year, depended on parturition interval, litter size, survival rate to weaning, and weaning weight. All of these factors, with the exception of litter size, were reported to improve as supplementation levels increased. From the regression line (Fig. 6), it was deduced that supplementation to dams with 100 g DM daily for the last 2 months of pregnancy and 3 months of lactation using a total of 14 kg browse DM raised the productivity index by 1.4 kg.

The fruits of some browse trees are also good sources of feed and protein. For example, livestock farmers in Africa are aware of the value of fruits of *Acacia* trees. In the Masai system in semi-arid Kenya, flocks are taken to *Acacia tortilis* woodland during dry periods to feed on ripe pods shaken from the trees by herdsmen. The pods make up about 50% of total daily intake during this period, and the animals gain weight. Conception rate were 80% for sheep and 54% for goats compared with 20 and 47% for control animals, respectively (de Leeuw et al.

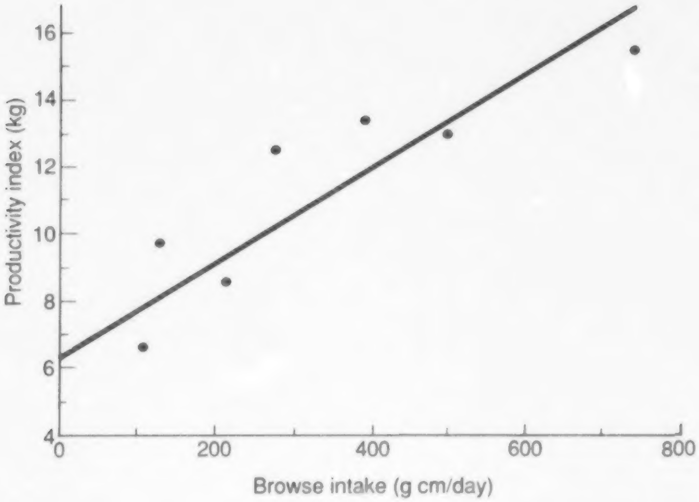

Fig. 6. Effect of browse intake on productivity of sheep (source: Reynolds et al. 1988).

Table 6. Growth rate, intake, true nitrogen digestibility and appearance of whole seeds in the feces of sheep fed noug cakes and fruits from four acacias, Addis Ababa, 1987.

	Noug cake	*Acacia tortilis*	*Acacia albida*	*Acacia nilotica*	*Acacia sieberiana*
Growth rate (g/day)	32.6a	32.3a	21.6ab	16.1b	0.4c
Maize stover intake (g/day)	483a	430b	401b	347c	320c
Fruit intake (g/day)	80	206	194	204	211
True N digestibility (%)	86a	81b	80b	80b	70c

Note: Means in the same row followed by the same letter(s) do not differ significantly ($P < 0.05$).

Source: ILCA (1988).

1986). An experiment conducted at ILCA to determine the nutritive value of fruits of four *Acacia* species (*A. albida*, *A. nilotica*, *A. sieberiana*, and *A. tortilis*), compared with noug cake (*Guizotia abyssinica*), showed that growth rate was highest in animals fed *A. tortilis* fruits and noug cake and lowest in those fed *A. sieberiana* (Table 6).

Limitations in the use of shrubs and tree fodders

Some browse plants contain biochemically active materials, such as cyanogenic glycosides, tannins, and goitrogenic and allergenic substances, that affect metabolism. For example, the seed pods of *A. nilotica*, relished by cattle, may be harmful if consumed in large amounts (Pratt and Gwynne 1977). Fruits of many *Acacia* species contain polyphenolic compounds that alter carbohydrate and protein use, decreasing urinary loss and increasing fecal N loss (ILCA 1987). The best known toxic principle in browse plants is probably that of leucaena, which contains mimosine, an amino acid derivative that in ruminants is normally degraded to the toxic 2,4-dihydroxy piridine (DHP). This can be harmful to livestock if leucaena is consumed in large quantities (Jones and Hegarty 1984).

Goats in Hawaii are able to thrive on diets composed mainly of leucaena for extended periods without signs of DHP toxicity (Jones 1981). Research has shown that this is due to the presence of a bacteria in the rumen that can metabolize the DHP into harmless products (Jones and Megarrity 1983). It has also been shown that, when kept under certain conditions, this bacteria can be transferred to other animals (see Kang et al. 1990). Such a transfer has been attempted in a joint project by ILCA and the West African Dwarf Goat Project in Nigeria with, as yet, inconclusive results (Ademosun et al. 1988).

When livestock are on free range, as in extensive production systems, they are hardly affected by the toxicity of browse. This is because of the variety of forage materials that are available.

Government policy on browse use

In the humid and subhumid zones, browse is freely lopped or grazed from fallow lands and natural pasture. The major problem with grazing in these zones is the encroachment on crop farms, leading to conflicts between livestock owners and crop farmers; there are bylaws in certain areas forbidding unherded or free-roaming animals during cropping seasons. There appears to be no government policy against lopping of browse or browsing in fallow land or rangelands. Land tenure rules in these zones may influence an individual's rights to harvest and use trees growing on particular types of land and to plant trees on such lands (Francis 1987). In some areas, just establishing trees on a piece of land may confer ownership rights on that land to the one who planted the trees. There is, therefore, some conflict between landowners and tenants with regard to planting of trees on rented or borrowed land.

In semi-arid and arid regions, the threat of desertification and the increasing role of livestock and fuelwood harvesting in it has resulted in widespread, far-reaching regulations against tree harvests. Legislation ranges from draconian rules, such as those prohibiting the carrying of a hatchet in some areas, to laws of little practical value, such as those listing protected species (Piot 1980). For example, according to Boudet and Toutain (1980) and Miche (1986), government policy forbids lopping throughout the Sahel. This measure was taken up by most Sahelian countries, and Article 39 of the Malian Forestry Code, passed on 17 February 1968, states that in the Sahel zone "the cutting, mutilating or felling of trees and shrubs for the purpose of feeding animals are strictly forbidden." Boudet and Toutain (1980) explain that in the context of this article, all pastoral land is legally subject to forestry regulations, and the "hand of man" is prevented from intervening to make browse available to livestock. Although justified by the ecological conditions and the increasing desertification, such regulations are difficult to enforce, and virtually inapplicable in these low-populated, extremely vast areas. Thus, the protection of trees, particularly browse trees, remains an unsolved problem, especially in the arid areas.

Conclusion

Shrubs and tree fodders play a significant role in livestock production in all agroecological zones of tropical Africa. Because of its generally high protein content, browse intake improves digestibility of low-quality feeds and leads to an overall increase in intake of digestible dry matter. Intake of browse, especially over critical periods such as the dry season, also results in increased survival and productivity of livestock.

There is a need for more research on the efficient cultivation, management, and use of fodder trees and shrubs for livestock production. Tree fodder production should be concentrated in high-potential areas such as the humid and subhumid zones, and fodder should be preserved and transported to the major livestock zones in the semi-arid and arid areas. Some more research is needed to improve the management and use of browse fodder to increase their effects on livestock productivity. The use of browse fodder in livestock diets should also be studied. Simple conservation and preservation techniques are required for the operation of such a system and to ensure that quality of forage is maintained.

The protection of trees, particularly browse trees, remains a major problem, especially in the dry areas. Governments should educate the local people on the dangers, both to livestock and to the environment, of over-exploitation, and initiate the organization of community-based efforts to improve and properly manage grazing reserves and rangelands. This can be done both through preservationist measures, as advocated by Boudet and Toutain (1980), and through enrichment planting of such reserves with preferred fodder trees. If well organized and managed, such reserves could be the basis of individual attempts at fodder preservation and range improvement, given favorable land tenure regulations, adequate education, and support by the government livestock and forestry sectors.

Acknowledgement

The valuable assistance provided by Mr I.V. Ezenva of the International Livestock Centre for Africa, Humid Zone Programme, in the literature search for this article is greatly appreciated.

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Potential of legume tree fodders as animal feed in Central America

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Abstract *— Agroforestry systems are promising alternatives for sustainable agricultural production in the subhumid and humid tropics of Central America. Intercropping* Erythrina poeppigiana *with coffee, African star grass (*Cynodon nlemfuensis*), or king grass (*Pennisetum purpureum × Pennisetum typhoides*); live fences of* E. poeppigiana *or* Gliricidia sepium*; and monocultures of the same two legume tree species (managed as protein banks) are systems analyzed in this paper, in terms of their forage biomass production potential, herbage quality, and nutrient cycling. Data generated in the Central American isthmus on the potential of legume tree foliages (mainly* E. poeppigiana *and* G. sepium*) as protein supplements for ruminants are also presented. Some of the aspects covered are chemical composition, in vitro dry matter digestibility, rumen degradability, intake, live weight gain, and milk production responses in goats, sheep, beef, and dairy cattle. Also, some information on the conservation of the foliage of* G. sepium *as silage is included.*

Résumé *— Les systèmes d'agroforesterie sont prometteurs de solutions de rechange allant dans le sens de l'agriculture durable pour les tropiques sous-humides et humides de l'Amérique centrale. Les auteurs analysent la culture intercalaire de* Erythrina poeppigiana *et du café, de* Cynodon nlemfuensis *ou de* Pennisetum purpureum × Pennisetum typhoides*; la plantation de haies vives de* E. poeppigiana *ou de* Gliricidia sepium*; et la monoculture des deux mêmes espèces d'arbres légumineux (gérés comme banques de protéines) en fonction de leur potentiel de production de biomasse fourragère, de la qualité des herbages et du cyclage des nutrients. Ils présentent les données obtenues dans l'isthme de l'Amérique centrale sur le potentiel des feuilles d'arbres légumineux (principalement* E. poeppigiana *et* G. sepium*) comme complément protéique à la ration alimentaire des ruminants. Ils abordent notamment la composition chimique, la digestibilité in vitro des matières sèches, la dégradabilité du rumen, l'ingestion, le gain de poids et la production de lait chez les chèvres, les moutons, le boeuf et la vache laitière. Également, ils donnent des informations sur la conservation des feuilles de* G. sepium *pour l'ensilage.*

Resumen *— Los sistemas de agroforestación, en los trópicos húmedos y semihúmedos de America Central, son alternativas promisorias para mantener la producción agrícola. El cultivo intercalado o intermedio de* Erythrina poeppigiana *con café, grama africana (*Cynodon nlemfuensis*) o grama rey (*Pennisetum purpureum × Pennisetum typhoides*), setos vivos de* E. poeppigiana *o* Gliricidia sepium *y monocultivos de las mismas dos especies de árboles leguminosos (explotados como bancos proteínicos) son sistemas que se analizan en este estudio, en función de su potencial de producción de biomasa forrajera, calidad de pastizales y ciclo de nutrientes. Se presentan los datos obtenidos en el Istmo de América Central con relación al potencial de* *follajes de árboles leguminosos (principalmente* E. poeppigiana *y* G. sepium*) como aditivos proteínicos para rumiantes. Entre los aspectos considerados se encuentran: composición química, digestibilidad de la materia seca in vitro, la capacidad de separación de alimentos del rumen, consumo, aumento en peso vivo y las respuestas de producción lechera en cabras, ovejas, ganado vacuno y lechero. Se incluye también información relativa a la conservación del follaje de* G. sepium *como ensilaje.*

Introduction

Agroforestry systems are a promising approach to developing sustainable, economical agricultural systems in the subhumid and humid tropics in Central America. Within this context, multipurpose nitrogen-fixing trees play an important role in smallholder farming systems. They provide fuelwood, live fences, shade for crops and animals, plant support, green manure, fodders, and medicinal and other products.

Since the late 1970s, the Tropical Agricultural Research and Training Centre (CATIE) has characterized the agroforestry systems used in the Central American isthmus and the Dominican Republic and developed more productive and sustainable systems using the agroforestry approach. CATIE has been studying several agroforestry alternatives using multipurpose nitrogen-fixing trees: intercropping trees in cocoa and coffee plantations as a source of shade and for recycling nutrients; alley cropping legume trees and annual crops; use of trees as support for trailing crops (e.g., black pepper and chayote squash); and as a source of fuelwood and posts. This paper emphasizes the potential use of *Erythrina* spp. and *Gliricidia sepium* as fodder sources for ruminants.

Forage biomass production

Forage biomass yield has been evaluated for five agroforestry systems that include nitrogen-fixing trees: intercropping of *Erythrina poeppigiana* with coffee, African star grass (*Cynodon nlemfuensis*), or king grass (*Pennisetum purpureum* × *Pennisetum typhoides*); live fences of *E. poeppigiana* or *G. sepium*; and monocultures of *E. poeppigiana* or *G. sepium* planted as "protein banks."

The use of *E. poeppigiana* as a shade tree in cocoa and coffee plantations is a traditional agroforestry practice in many areas of the tropics (Budowski 1959; Cadima and Alvim 1967; Willey 1975). Several effects have been mentioned: soil and crop temperatures decrease; radiation is reduced, affecting photosynthesis, stomata opening, flowering, and fruit ripening; transpiration is diminished; nutrients are recycled into the soil; and nitrogen fixation occurs when legume trees are used. In this system, the biomass yields and the amount of nutrients recycled are a function of the pruning interval used for the shade tree. They also depend on the spacing of planted shade trees and the age of the plantation. Total biomass yield increases as the pruning frequency decreases. The reverse occurs for leaf yields (Table 1), indicating that the proportion of edible biomass is greater with more frequent prunings (Russo 1984).

A similar trend to that mentioned for total biomass occurs for the amount of nutrients recycled through pruned and fallen leaves of *E. poeppigiana*. The average

Table 1. Annual biomass production (kg/ha) from *E. poeppigiana* pruned at different frequencies in a Costa Rican coffee plantation.[a]

Number of prunings per year	Leaves	Stems	Total
1	3 270	15 200	18 470
2	3 900	7 700	11 800
3	4 340	3 510	7 850

Source: Russo (1984).

[a] In plantation, 280 trees/ha, 6 × 6 m spacing.

values for annual recycled nitrogen, phosphorus, potassium, calcium, and magnesium are 257, 22, 142, 180, and 55 kg/ha, respectively (Russo 1984). If all the edible biomass of *E. poeppigiana* is extracted for animal feeding, then the most easily mineralizable fractions are removed from the field. The sustainability of these systems is, therefore endangered, unless organic or chemical fertilizers are applied.

The second agroforestry system studied was the intercropping of *E. poeppigiana* with African star grass. This was compared with intercropping African star grass with a timber tree (*Cordia alliodora*) and with a control (no trees). Annual grass dry matter yield was higher when associated with the legume tree than with the timber tree (9 311 vs 4 087 kg/ha). The lowest annual yield (2 632 kg/ha) was obtained in the control plots. Also, there were broad-leaved weeds in those plots with trees. Even though the presence of trees negatively affected solar radiation reaching the grass canopy (60% of that measured in the unshaded plots), the nutrients recycled through fallen leaves and pruned branches, and nitrogen fixation occurring in the legume tree plots, favoured grass growth and prevented the invasion of weeds. A significant increase in the grass crude protein (CP) content was also observed in the *E. poeppigiana* plots compared with those plots with *C. alliodora* and without trees (9.5, 6.4, and 6.1% CP, respectively). This suggests that the legume tree effectively fixed and transferred nitrogen to the grass (Bronstein 1984).

The third agroforestry system evaluated was the intercropping of king grass (*P. purpureum* × *P. typhoides*) and *E. poeppigiana* under a cut-and-carry approach (Rodríguez 1985). In this system, the annual grass yield was not affected by the presence of trees (17.7 and 16.8 t dry matter (DM)/ha for plots with 1 666 and 3 333 trees/ha, respectively), indicating that the nutrients transferred by the legume tree compensated for the lower radiation that reached the grass canopy. Other beneficial effects of this system were the extra amount of a nitrogen-rich foliage produced annually by the legume tree (7.6 and 11.6 t DM/ha for plots with 1 666 and 3 333 trees/ha, respectively) and the slight increase observed in the CP content of the grass growing under the trees. The productivity of this system declined with time, however, because of the high removal of nutrients through the grass and legume tree biomass, which, in general, was greater in the intercropped than in the monoculture grass plots. The average annual extractions of nitrogen, phosphorus, and potassium in the intercropped treatments were 444, 71, and 396 kg/ha, respectively; the corresponding values for the control plots were 151, 59, and 345 kg/ha. This experiment has now been modified to assess the sustainability of the system, when different proportions of the biomass obtained after pruning the legume tree are returned as green manure.

The fourth agroforestry system considered was the use of legume trees (*G. sepium* or *Erythrina berteroana*) as live fences, a common practice in the humid and subhumid tropics of Central America. Different pruning intervals have been evaluated at four sites in the lowland humid tropics of Costa Rica (CATIE 1987). Several factors are known to affect biomass production in this system (Fig. 1), including age of live fence, distance between trees, and pruning frequency. In general, the total biomass yield increased as the pruning interval was delayed (Table 2), but the proportion of edible biomass declined with age. Also, tree survival was negatively affected by frequent pruning. To obtain a sustained productivity of such systems, the pruning interval has to be at least 4 months (CATIE 1987).

Because of the limited yield that can be obtained from the live fence agroforestry system, a new strategy has been tested. Stakes of *G. sepium* and *E. berteroana* have been planted similarly to sugarcane, to establish legume tree "protein banks." The average annual yields obtained during the 1st year were 19.4 and 27.0 DM/ha for *G. sepium* and *E. berteroana*, respectively (CATIE, unpublished data). Whether or not these high yields can be sustained needs to be investigated.

Fig. 1. Measuring foliage production from a live fence of *Erythrina berteroana* in the lowland humid tropics of Costa Rica.

Table 2. Annual biomass production (kg dry matter/km) from live fences of *E. berteroana* and *G. sepium* pruned at different frequencies in the lowland humid tropics of Costa Rica.

Pruning intervals (months)	Edible biomass	Total biomass
	E. berteroana	
2	1 058–2 168	1 058–2 168
4	1 769–3 976	3 132–6 201
6	1 435–4 218	3 189–8 273
	G. sepium	
2	139–1 244	139–1 244
4	1 001–5 580	1 581–7 771
6	353–3 546	589–7 483

Note: Results are ranges of values obtained at four research sites.
Source: CATIE (1987).

Nutritive value

The edible biomass of legume trees is a useful protein supplement for ruminants. Efforts have been made to characterize the nitrogen fraction of these feedstuffs (Espinoza 1984). The CP content varies with plant portions (laminae green stem petiole); however, the rumen degradability of the nitrogenous fraction does not follow the same pattern (green stem petiole laminae). In general, these forages have shown higher DM rumen degradability values when in situ digestion techniques have been used (Table 3), compared with the traditional in vitro dry matter digestibility (IVDMD) method. This suggests that some antiquality factors are present, especially in the more mature laminae (Table 4). Also, the solubility of the nitrogenous fraction is particularly high in the green stem, but lower in the petiole and laminae. In all three portions, more than 75% of the soluble fraction is represented by nonprotein nitrogen (NPN) compounds (Espinoza 1984).

Most of our work on the quality of legume tree foliages has concentrated on two species: *E. poeppigiana* and *G. sepium*. More recently, however, the nutritional diversity of the genus *Erythrina* has been studied (CATIE, unpublished data). The results obtained show important variations among and within species in terms of CP content, protein solubility, acid-detergent insoluble nitrogen (ADIN) content, and IVDMD (Table 5). These results showed that the *Erythrina* species most commonly included in the agroforestry systems previously evaluated (*E. poeppigiana* and *E. berteroana*) had a higher nutritional quality than the less common *E. fusca* and *E. costarricense*, notwithstanding the variability in the nutritive value of *E. berteroana*. These results suggest the need for a better definition of the germ plasm used in different experiments, as well as the potential for genetic improvement of quality parameters in these species.

Another important aspect that needed clarification with respect to these nontraditional forages was the extent of the acceptability by animals. Benavides (1986) showed that the DM intake of *E. poeppigiana*, as the sole forage source for goats, was as high as that obtained for the herbaceous legume *Lablab purpureus* (3.24 and 3.39% body weight, respectively). Some differences among legume tree foliages, in terms of their potential intake, have been detected by Arguello et al.

Table 3. Nitrogen fractions in different portions of the edible biomass of *G. sepium* and *E. poeppigiana* harvested at 3- and 5-month intervals.

	G. sepium		*E. poeppigiana*	
Fraction	**3 m**	**5 m**	**3 m**	**5 m**
Crude protein (CP) (%)				
Laminae	23.8	26.9	26.0	30.3
Petiole	11.9	12.5	9.3	10.4
Green stem	20.7	18.9	17.8	22.4
N rumen degradability (%)				
Laminae	79.3	76.7	67.2	61.8
Petiole	80.1	77.2	78.8	78.3
Green stem	86.8	81.4	83.9	89.7
CP solubility (%)				
Laminae	23.6	37.8	26.3	24.4
Petiole	43.7	54.2	47.0	54.8
Green stem	63.7	70.7	67.2	60.2
Nonprotein nitrogen (% soluble CP)				
Laminae	82.8	77.6	87.5	76.6
Petiole	82.0	78.8	80.4	80.2
Green stem	91.9	85.5	93.4	89.7
ADIN (% total N)[a]				
Laminae	42.1	44.6	23.1	33.0
Petiole	33.6	32.0	32.3	38.5
Green stem	14.5	10.6	11.2	13.4

Source: Espinoza (1984).

[a] ADIN, acid-detergent-insoluble nitrogen.

Table 4. Nutritive value of the edible biomass in *E. poeppigiana*, as a function of position in the branches.

Stratum (cm from branch apex)	**CP (%)**		**IVDMD (%)**	
	Laminae	**Petiole**	**Laminae**	**Petiole**
0–40	31.9a	12.4a	60.0a	72.0a
40–80	29.8b	9.2b	49.7bc	66.1b
80–120	28.8bc	8.6b	50.0bc	67.0b
120–160	26.5d	8.4b	48.1c	63.3b
160–200	28.3c	9.2b	52.8b	67.4b

Note: CP, crude protein; IVDMD, in vitro dry matter digestibility. Means followed by the same letter in the same column do not differ statistically ($P \leq 0.05$).

Source: Russo (1984).

(1986) and Vargas and Elvira (1987), using goat kids and dual-purpose cattle. In both studies, the foliage of *G. sepium* was the most readily consumed (Table 6); however, several experiments performed at CATIE have indicated that ruminants have no palatability problems with the commonly used species of *Erythrina*, whereas problems of intake have been detected in some studies with *G. sepium*. Studies to clarify the causes of this problem in *G. sepium* are needed. There is some evidence of genetic variability in the content of antiquality factors in this species; but some seasonal and age of regrowth effects may also exist.

Table 5. Nutritive value of the edible biomass in different species and clones of the genus *Erythrina*.

Species	No. of clones	Crude protein (%)	Protein solubility (%)[a]	ADIN (%)[b]	IVDMD (%)[c]
E. berteroana	12	25 (22–28)[d]	40 (28–53)	10 (7–13)	49 (42–55)
E. fusca	7	23 (19–25)	32 (20–49)	14 (10–18)	44 (43–47)
E. poeppigiana	3	32 (31–32)	49 (44–60)	9 (7–11)	52 (50–54)
E. costarricense	8	25 (22–27)	39 (28–46)	14 (8–19)	46 (32–53)
E. cocleata	1	24	35	20	47
E. lanceolata	1	26	56	14	50

[a] Solubility in a borate–phosphate buffer.
[b] ADIN, acid-detergent-insoluble nitrogen, % of total nitrogen.
[c] IVDMD, in vitro dry matter digestibility.
[d] Values in parentheses are the ranges of mean values for clones within species.

Table 6. Chemical composition, in vitro dry matter digestibility (IVDMD), and voluntary intake of *Leucaena leucocephala*, *Gliricidia sepium*, and *Guazuma ulmifolia*.

	Leucaena	*Gliricidia*	*Guazuma*
CP (%)	25.0	25.8	14.7
CWC (%)	47.8	43.5	49.5
ADF (%)	28.2	26.2	31.4
ADIN (% of total N)	7.4	10.7	25.2
IVDMD (%)	47.8	58.4	43.0
DM intake[a] (% body weight)	0.512c	0.868a	0.709b

Note: CP, crude protein; CWC, cell wall constituents; ADF, acid-detergent fibre; ADIN, acid-detergent-insoluble nitrogen; DM, dry matter. Means followed by the same letter do not differ statistically ($P \leq 0.05$).

Source: Vargas and Elvira (1987).

[a] Ad libitum intake obtained in 2 h after the morning milking.

Silage conservation

The need for protein supplementation in grazing animals is enhanced during the dry season in subhumid ecosystems. However, in many legume trees, the protein-rich leaves are unavailable for animal feeding during this part of the year because leaves are shed during the early dry season, when plants enter a flowering stage (Russo 1984). One of the strategies considered to overcome this restriction is conserving these foliages as silage. This task is not easy, however, because, in many cases, the fermentation process in legumes is dominated by Clostridia, leading to a butyrate-type silage. This has been attributed to three factors in the legumes: high buffering capacity, low water-soluble carbohydrates, and, often, low DM content. Based on these facts, different preconditioning treatments to reduce nutrient losses during silage fermentation have been tested.

Kass and Rodríguez (1987) observed that a high proportion of the nitrogen fraction was in a volatile form (ammonia) and low levels of lactic acid were detected in silages made of either fresh or wilted *G. sepium* foliage, without additives. The addition of readily fermentable carbohydrate sources, such as molasses or chopped sugarcane, decreased ammonia and increased lactic acid concentrations. Also, the addition of formic acid markedly reduced ammonia nitrogen, but did not affect lactic acid production.

Based on these preliminary results, different levels of sugarcane molasses as an additive for *G. sepium* silages were evaluated (CATIE, unpublished data). The CP content tended to decline slightly (dilution effect), but IVDMD increased as higher levels of molasses were added. A decline in ammonia concentration occurred when 2% molasses (w/w) was added to ensiled *G. sepium*, but higher levels of molasses resulted in minor changes in ammonia concentration. Lactic acid concentration increased almost linearly with molasses additions, but the highest level of molasses (10%, w/w) resulted in a silage with only 2.6% lactic acid. In all cases, the butyric acid concentration was very low (0.04%). The voluntary intake of these silages has not been measured, but observations with young female goats showed that silages made of *G. sepium* with 2% molasses as an additive were readily consumed when fed as a supplement to chopped grass.

Animal production responses

Small ruminants

Initial work has been done at CATIE, using goats and sheep, aimed at developing ruminant feeding systems based on the use of legume tree foliages as protein supplements. In most of these studies, the basal diet was chopped king grass (*P. purpureum* × *P. typhoides*); this has been supplemented with different energy sources, especially green bananas.

Gutiérrez (1983) compared *E. poeppigiana* foliage plus green bananas with a commercial concentrate as supplements for dairy goats receiving chopped king grass as the basal forage source. Daily milk yield was greater with goats fed the commercial concentrate than with those fed *E. poeppigiana* and bananas (1.29 vs 1.08 kg/head); however, the former showed lower daily gains (9 vs 59 g/head), and the economic analysis favoured the use of *E. poeppigiana* plus green bananas. These findings encouraged further research in this field.

Samur (1984) examined whether the use of a starch source (green bananas) would result in a milk production higher than that obtained with a sugar-rich source (ripened bananas). The rationale was not only that starch promotes microbial protein synthesis in the rumen when readily degradable protein sources are used but also that some starch escapes ruminal degradation, therefore increasing glucose availability for milk synthesis and other purposes. The results supported this hypothesis: slightly higher daily milk yields were obtained when green rather than ripened bananas were used as the energy supplement (1.28 vs 1.23 kg/head, respectively). However, this effect was more evident in two other experiments done with weaned lambs (Benavides and Pezo 1986) and goat kids (Benavides and Esnaola 1986). In both studies, the advantages of using either starch- or a mixture of sugar- and starch-rich sources as energy supplements to diets based on legume tree foliage were demonstrated.

Table 7. Milk production and dry matter (DM) intake in goats supplemented with two levels of *E. poeppigiana* and plantain fruits.

Response variable	HP		LP	
	HE	LE	HE	LE
Daily milk yield (g/head)	1 270a	1 090b	1 090b	1 110ab
Milk fat (%)	3.4	3.3	3.3	3.1
Daily DM intake (kg/head)				
Chopped king grass	0.77	0.93	0.96	0.97
E. poeppigiana	0.45	0.32	0.45	0.32
Plantain fruits	0.60	0.60	0.37	0.37
Daily LW gain (g/head)	170	50	20	50

Note: H, high; L, low; P, plantain fruits; E, *E. poeppigiana*; LW, live weight. Means followed by the same letter do not differ statistically ($P \leq 0.05$).

Source: CATIE (unpublished data).

Esnaola and Rios (1986) offered different levels of supplementary *E. poeppigiana* foliage to goats. Milk yield increased linearly as a response to the level *E. poeppigiana* used. Also, a partial substitutive effect of the supplement on the intake of chopped king grass was detected, resulting in an additive effect on total DM intake.

A recent factorial experiment (CATIE, unpublished data), in which two levels of both *E. poeppigiana* foliage and plantain fruits were evaluated as supplements to a chopped king grass basal diet for milking goats, showed that the highest milk yield corresponded to the combination of the highest levels of both supplements (Table 7). However, the interesting aspect of this study is that the second highest milk production was obtained for the combination of the lowest levels of both supplementary sources. As both treatments had about the same CP/DE (digestible energy) ratio, perhaps a given ratio of both nutrients should be maintained for efficient milk production.

Most of the small ruminant feeding experiments carried out at CATIE using legume tree foliages have used *E. poeppigiana*. There is one direct comparison of this species with *G. sepium* (Rodríguez et al. 1987): higher milk yields were obtained when goats were fed *E. poeppigiana*. Both tree foliages showed similar values for chemical composition, but the lower DM intake observed in the case of *G. sepium* negatively affected daily milk production (1.26 and 1.11 kg/head for *E. poeppigiana* and *G. sepium*, respectively). It is clear that there is a need for a more detailed study on the causes of limited intake in some *G. sepium* foliages, because previous work from other regions (e.g., Chadhokar 1983) has not detected this type of problem.

Cattle

Few studies have been done at CATIE evaluating the use of legume tree foliages as protein supplements for cattle; again, *E. poeppigiana* has been the main species evaluated. The first experiment was done with weaned dairy heifers, evaluating different levels of substitution of a traditional protein source (soybean meal) with *E. poeppigiana* foliage (Pineda 1986). The replacement of soybean with increased levels of *E. poeppigiana* resulted in lower daily gains (Table 8), confirming that the protein quality of this tree foliage is less than that of soybean meal. From an economic viewpoint, however, the best results were obtained when 67% of the protein requirements were provided by *E. poeppigiana*.

Vargas (1987) fed growing bulls different levels of *E. cocleata* foliage and observed increased live weight gain when *E. cocleata* was offered at a level equivalent to 0.5% body weight (398 and 524 g/day, for the control and 0.5% body weight for *E. cocleata*). Also, the addition of an energy supplement (green banana fruits) to the same level of *E. cocleata* resulted in a slight increase in daily gain (579 vs 524 g/head).

The use of *E. poeppigiana* and sugarcane molasses as supplements for milking cows grazing African star grass, instead of commercial concentrates (Abarca 1989), have consistently resulted in lower milk yields (8.4 and 8.0 kg/day, for concentrate and *E. poeppigiana* supplementation, respectively). Minor changes in milk composition were also observed. However, when *E. poeppigiana* was compared with fish meal as a protein supplement for milking cows, higher milk yields were obtained with the fish meal (Table 9), confirming that this legume tree foliage has a lower protein quality. Economic analyses of our dairy cattle experiments have indicated that there are no differences in the net profit obtained using the traditional (fish meal or commercial concentrates) or nontraditional supplements (legume tree

Table 8. Intake, in vivo digestibility, and daily live weight gain (LWG) in heifer calves fed different proportions of soybean meal (SMB) and *E. poeppigiana* (P) foliage as a protein supplement.

Response variable	100% SBM	67% SBM, 33% P	33% SBM, 67% P	100% P
Intake (% body weight)				
Soybean meal	0.46	0.31	0.15	0.0
E. poeppigiana	0.0	0.26	0.52	0.79
King grass	2.19	2.04	1.93	1.80
Sugarcane molasses	0.86	0.97	1.01	1.15
Digestibility (%)[a]				
DM	62	60	60	58
CWC	62	55	55	53
LWG (g/head)	410	366	372	294

Source: Pineda (1986).

[a] DM, dry matter; CWC, cell wall constituents.

Table 9. Dry matter (DM) intake and daily milk production in cows grazing African star grass, supplemented with either fish meal or *E. poeppigiana* foliage as the protein source.

	Fish meal	*E. poeppigiana*
DM intake (% body weight)		
African star grass	1.93a	1.24b
Supplement	1.08a	1.55a
Total	3.01a	2.79a
Milk production (kg/head)	9.0	8.2
Milk compostion (%)		
Total solids	13.4b	12.7a
Protein	3.2a	3.3a
Fat	4.1a	4.3a

Note: Sugarcane molasses was the energy supplement. Means in the same row followed by the same letter do not differ significantly ($P \leq 0.05$).

foliages plus locally available energy sources, such as green bananas). There is an important advantage favouring nontraditional supplements: i.e., lower cash costs. This is important for the small farmer because the availability of cash is one of the farmer's main constraints.

Another experiment, carried out by Tobón (1988), showed a linear increase in milk production as the level of *E. poeppigiana* foliage increased. The equation describing this linear relationship was $Y = 8.75 + 1.29X$, where Y is daily milk yield (kilograms per cow) and X is DM intake (percent body weight).

In summary, the results obtained with grazing dairy cows under lowland humid tropical conditions suggest that the direct benefits on milk production derived from the use of *E. poeppigiana* foliage are small, but that there might be important indirect benefits. These benefits include increased carrying capacity as a result of substitutive effects on grass intake and increased recycling of nutrients in the areas grazed, through richer animal excretas. These aspects need to be investigated in future work.

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Availability and use of shrubs and tree fodders in Pakistan

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Abstract *— Despite efforts to increase fodder production in Pakistan, livestock farmers experience traditional periods of shortage in May–June and October–November. Shrubs and trees are potentially important and merit attention, especially in areas where conventional agriculture may not be possible or desirable because of dangers of site degradation; steep and rocky slopes; arid, saline, or water-logged soils; or severe climatic conditions. Some promising exotic and indigenous fodder trees and shrubs have been selected for plantation in various ecological zones of Pakistan. Animals depend on these shrubs and trees, especially in arid zones, but wider use is limited by the fact that the nutritional value of most species has not been demonstrated. Factors affecting the usefulness of shrubs and tree fodders also need to be determined.*

Résumé *— Malgré les efforts déployés pour accroître la production de fourrage au Pakistan, les éleveurs de bétail traversent encore des périodes de pénurie de fourrage, habituellement en mai–juin et en octobre–novembre. Les arbustes et les arbres présentent un potentiel important et méritent notre attention, surtout dans les régions où l'agriculture conventionnelle n'est peut-être ni possible ni souhaitable en raison des dangers de dégradation des sites: pentes abruptes et rocheuses; sols arides, salins ou saturés d'eau; ou conditions climatiques difficiles. Quelques arbustes et arbres fourragers indigènes et exotiques, qui semblaient prometteurs, ont été plantés dans différentes zones écologiques pakistanaises. Les animaux, surtout dans les zones arides, se nourrissent de ces arbustes et arbres, mais le fait que la valeur nutritive de la majorité de ces espèces fourragères n'a pas été prouvée en limite l'exploitation plus répandue. Il faut aussi déterminer les facteurs qui influent sur l'utilité des arbustes et arbres fourragers.*

Resumen *— A pesar de los esfuerzos destinados a incrementar la producción de forraje en Paquistán, los ganaderos atraviesan períodos tradicionales de escasez de mayo a junio y de octubre a noviembre. Los árboles y arbustos son potencialmente importantes y merecen ser tenidos en cuenta, especialmente en zonas en que la agricultura tradicional puede no ser posible o deseable, debido a los peligros de la degradación del terreno: laderas empinadas y rocosas, suelos áridos, salinos o húmedos; o duras condiciones climáticas. Se seleccionaron algunos árboles y arbustos forrajeros naturales de potencial promisorio para su plantación en varias zonas ecológicas de Paquistán. Los animales dependen de estos arbustos y árboles, especialmente en zonas áridas, pero no se utilizar más ampliamente pues no se ha demostrado el valor nutritivo de la mayoría de las especies. Es necesario determinar también qué los factores afectan la utilidad de arbustos y árboles forrajeros.*

Introduction

Pakistan has 30.6 million large ruminants (buffaloes and cattle) and 58.5 million small ruminants (sheep and goats) (Nawaz et al. 1988). By the year 2000, populations for the major species will be approximately 19.2 million cattle, 24.8 million buffaloes, 36.6 million sheep, and 56.8 million goats (Anon. 1987). There is an annual shortage of digestible crude protein (DCP) and total digestible nutrients (TDN) of about 1.6 and 12.5×10^6 t, respectively (Akram 1987).

Considerable on-station research has been done since 1975, and the data clearly show that fodder crops production can be increased 50–100%. Despite this information, livestock farmers still experience two traditional stress periods of fodder and forage shortage: May–June and October–November. This results in livestock achieving only 75–80% of inherent productive capacity. To overcome this, it has been recommended that studies be initiated with shrubs and fodder trees. The increasing animal population will require a 51% increase in feeds over the current supply. The current feed deficiency implies that the future generation of livestock will be underfed as in 1988, or perhaps even more because of anticipated increased genetic potential through breeding and up-grading (Crowder 1988).

Value of shrubs and tree fodders

Green fodder production on cultivated land is handicapped by the lack of area for fodder production, the lack of irrigation facilities and other inputs, and low economic returns from fodder crops compared with cash crops. Trees that can be grown either in combination with agricultural crops or on land usually unfit for agriculture offer the opportunity of producing nutritious fodder for livestock. It is seldom realized that probably more animals are fed on shrubs and tree fodders than on grasses. Also, some tree fodders are almost as nutritious as leguminous fodder crops.

Trees can produce as much, if not more, green fodder per unit area than fodder crops. Furthermore, trees are capable of growing under conditions and in areas where it may be impossible to grow conventional agricultural crops, such as on steep and rocky mountain slopes, in arid, saline, or water-logged soils, and in areas with severe climatic conditions. The ability of trees to tap water from deep underground layers and to withstand drought is another outstanding advantage. Trees do not need heavy inputs of fertilizers, pesticides, fungicides, and labour, as do agricultural crops. Also, fodder production from trees will make available fuelwood as a by-product, which will help the rural population meet their energy requirements. Trees, therefore, deserve attention for the production of nutritious fodder for livestock, especially in areas where conventional agriculture may not be possible or desirable because of the dangers of site degradation (Singh 1978).

The potential of trees and shrubs for green fodder production is not fully appreciated except in hilly or desert areas, where they are a major source of green fodder for livestock. One reason for this is that the nutritional value of most trees and shrubs has not been demonstrated (Singh 1978). The preference for tree fodders also differs with the regions.

Nutritive value

The potential of trees and shrubs as livestock feed is being increasingly recognized. It is a surprising realization that more animals feed on shrubs and trees than on grass. This is true in arid zones all over the world (Khan 1965).

It is difficult, however, to lay down general rules about what makes a good browse species. It is initially important to know the relative nutritive value of grasses and shrub vegetation. The nutritive value of shrubs and tree fodders fluctuates much less than that of grasslands. In the arid areas of Pakistan, the vegetation has been reduced to a very low level of ecological succession because of overgrazing; under such circumstances, the importance of fodder trees and shrubs greatly increases. To keep the shrub cover productive and to avoid soil erosion, it is essential that grazing be well-managed and adjusted to the rate of recovery of shrubs in pastureland. In arid areas, the livestock population is generally greater than what the land can support. Under these circumstances, the cultivation of trees and shrubs assumes great importance. However, indiscriminate lopping often results in the death of desirable trees and shrubs (Khan 1965).

Trees and shrubs not only provide fodder for the livestock but may also be useful in providing fuel. A system of alternate husbandry has become established in some areas of Sind, where *Acacia* is the main cultivated genus. Although *Acacia* is primarily grown for fuel, its leaves and pods are used as fodder when other types of fodder are in short supply. Pods supplement and extend the critical fodder period. *Acacia* leaves are valued for their nutritive value and milk-improving quality during the cold months of the year, but their use must be restricted if the plants are to flower and produce pods. *Acacia* is cultivated in rows about 10–12 m apart, and the land in between is used for cropping until the trees mature. *Prosopis specigera* is an important tree in arid areas in Sind (Khan 1965).

In hilly regions, trees and shrubs are lopped in forested areas. Because of the larger livestock population, the absence of a proper management system and rotation, and wasteful methods of feeding animals, fodder trees have disappeared in such areas (Khan 1965).

The utility of trees as an integral component of pastureland is also determined by suitability of species, needs of animals, soils, etc. Trees and shrubs also act as windbreaks. In arid zones, where superficial moisture is much less, trees are important for both shade and feed in pastureland. Thus, it is obvious that more consideration should be given to trees and shrubs in the management of rangeland and pastures (Khan 1965).

National Forage and Fodder Research Program

In 1974, a working group on fodder and forage research met in Islamabad to review the state of the art and make recommendations regarding future programs. A conceptual framework was proposed within which a National Forage and Fodder Research Program was developed. Thus, the Coordinated National Research Program was implemented in July 1975 for a period of 5 years: 1975–1980. The program was to be undertaken at the National Agricultural Research Centre, Islamabad, and at agricultural and livestock research institutes in four provinces.

The range and forage research was to be carried out at research stations in Pakistan's different ecological regions: tropical maritime (Dhabji, Sind), tropical plains (Thal, Punjab), subtropical (Islamabad and Pakistan Forest Research Institute, Peshawar, NWFP), mediterranean (Hazara, NWFP, Gunje, Quetta, Baluchistan), Himalayan subtropical (Jaba, NWFP), and Himalayan temperate (Dirkot, Azad Kashmir).

Because of limited funding, the proposed research was not supported at all locations. Nevertheless, through commendable efforts and activities, encouraging results have been achieved, especially at the National Agricultural Research Centre, Islamabad; Fodder Research Institute, Sargodha; Ayub Agriculture Research Institute, Faisalabad; and Livestock Production Research Institute, Bahadurnagar. Supplementary information has also been obtained from the University of Agriculture, Faisalabad; Agricultural Research Institute, Sariab, Quetta, Tandojam, Sind; and Tarnab, NWFP. The National Fodder and Forage Research Program was thus extended. In 1985, the program was separated to form two different divisions:

- the National Cooperative Fodder Research Program and
- the National Cooperative Forage Program.

Fodder crops in Pakistan include all crops that are used as cut-and-carry feed for livestock. Pastures and forage include all vegetation grazed and browsed by livestock, with particular reference to rain-fed flat lands, hilly areas, and rangelands. There is no clearly defined responsibility for fodder trees and shrubs that are lopped for feeding or browsing. Considerable information has been collected in various stations and institutions engaged in fodder crops research. The salient achievements are as follows:

- High-yielding varieties of *Egyptian clover* lucerne, *Avina sativa* sorghum, millet, and maize have been developed.
- Multicut fodders, i.e., Bajra–Napier hybrid (*Pennisetum* hybrid) and SS-hybrid (sorghum–Sudan grass), have been developed.
- Production technologies for improved cultivars have been standardized.
- Quality of the different fodders and forages evolved have been determined through biochemical and biological evaluation.
- Production of prebasic seeds of high-yielding varieties of fodders has been initiated.

Despite these notable results, the fact remains that the farmer is experiencing the two stress periods that hamper animal performance (Muhammad and Naz 1985).

Availability and use of shrubs and tree fodders

Khan (1965) has compiled information, probably based on surveys, on the availability and use of shrubs and tree fodders in Pakistan. Yaqub and Chughtai (1979) compiled information on the chemical composition and nutritive value of indigenous feedstuffs. The mineral composition of shrubs and tree leaves as well as digestion coefficients of dry matter and crude fibre of some tree leaves were also reported.

During the past 23 years, the Pakistan Forest Research Institute, Peshawar, and the provincial forestry departments have helped to introduce several exotic, fast-growing fodder and fuel trees and shrubs in the various ecological zones of Pakistan (Table 1).

Recently, *Leucaena leucocephala* was introduced at the farmer level as well as at the Livestock Experiment Station within the agroforestry program of Farming Systems Research (FSR). Postgraduate students in the Department of Livestock Management, University of Agriculture, Faisalabad, have been studying the comparative nutritive value of *L. leucocephala*, *Acacia arabica*, *Zizyphus jujuba*, and *Morus nigra* for small ruminants. The research will focus on the proximate composition, digestibility of nutrients, and production performance by the animals.

A research project on the use of shrubs and fodder tree leaves by farm animals involving multidisciplinary teams and researchers from the Departments of Animal Nutrition, Livestock Management, Veterinary Pathology, and Veterinary Pharmacology and Physiology, University of Agriculture, Faisalabad, is being formulated. The proposed research project and the work already initiated under the FSR program will go toward educating farmers in the use of shrubs and tree

Table 1. Fodder trees and shrubs suitable for plantation in various ecological zones in Pakistan.

Ecological zone	Species
Subalpine, temperate	*Amorpha fruticosa*, *Indigofera geradiana*, *Prunnus padus*, *Fraxinus excelsior*, *Aesculus indica*, *Alnus nepalensis*, *Celtis australis*, and *Quercus dilatata*
Subtropical, humid	*Amorpha fruticosa*, *Grewia oppositifolia*, *Prunnus* spp., and *Robinia pseudoacacia*
Subtropical, subhumid	*Acacia modesta*, *Acacia aneura*, *Ceratonia siliqua*, *Leucaena leucocephala*, and *Olea cuspidata*
Arid and semi-arid desert plains	*Acacia arabica*, *Acacia modesta*, *Acacia senegal*, *Prosopis cineraria*, *Tecoma undulata*, and *Zizyphus mauritiana*
Mediterranean	*Atriplex canescens*, *Caragana ambigua*, and *Pistacia khinjuk*

Source: Muhammad and Naz (1985).

fodders. Among native species, *Prosopis cineraria, Acacia nilotica, Tecoma undulata, Acacia senegal, Zizyphus nummularia, Caligonum polygonoides*, and *Indigofera oblongifolia* are suggested for revegetation of the arid area of Sind. Planting exotic species such as *Acacia aneura, Atriplex numularia*, and *Opuntia* spp. is also recommended (Muhammad 1984). *Leucaena leucocephala, Acacia aneura, Acacia tortilis, Tamarix dioca, Atriplex numularia*, and *Opuntia ficus indica* have successfully been planted in the Kohistan tract of Sind (Muhammad 1984). *Zizyphus nummularia, Zizyphus jujuba*, and *Prosopis cineraria* have been planted over large areas of Thal in Punjab (Khan 1965).

Recommendations

A number of recommendations are suggested:

- A comprehensive survey is necessary on the availability and use of shrubs and tree fodders.
- Productivity of rangelands can be increased by planting selected fodder trees and shrubs.
- To meet the firewood and fodder demand, planting of fast-growing fuel and fodder trees and shrubs needs to be encouraged in all ecological zones.
- Collaborative research is necessary between animal nutritionists and bacteriologists to determine if the mimosine bacterium exists in the microflora of ruminants.
- The potential benefits of small ruminant production systems integrated with tree cropping, including fencing, needs to be explored.
- Parallel work with agroforestry programs also needs to be strengthened.

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Agrosilvipasture systems in India

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Abstract — *Agrosilvipasture systems have evolved in response to pressures of both animal and human populations coupled with changing climatic regimes. The systems, integrating trees or woody perennials and grasses with crop farming, ensure stability in land productivity, achieve high productivity and diverse produce, improve soil fertility, and enhance the supply of nutritious fodder to livestock in varied agroecological conditions. Agrosilvipasture systems, when compared with traditional land-use systems, have much higher yields and year-round forage availability. Potential fodder trees, grass species, and production systems have been identified for specific situations. The systems, besides being economical, result in ecological improvement and show great promise for enhancing biomass production and meeting the increasing demand for forage and fuel wood. Each of these aspects, including the use of trees and shrubs and research and extension needs, are discussed in this paper.*

Résumé — *Les systèmes agrosylvipâturaux ont évolué en réponse aux pressions exercées par les populations animales et humaines combinées aux changements dans les régimes climatiques. Les systèmes, qui intègrent les arbres ou plantes ligneuses et les graminées aux cultures, garantissent la stabilité de la productivité des sols, permettent une productivité élevée et diversifiée, augmentent la fertilité des sols et améliorent l'approvisionnement en fourrages nutritifs pour le bétail dans diverses conditions agroécologiques. Les systèmes agrosylvipâturaux, comparés aux systèmes conventionnels d'exploitation des terres, ont un rendement beaucoup plus élevé et assurent une disponibilité plus grande de fourrage sur toute l'année. On a déterminé quels arbres fourragers, espèces de graminées et systèmes de production conviendraient sans doute dans certaines situations. Les systèmes, outre qu'ils soient économiques, entraînent une amélioration de l'écologie et offrent de grandes promesses d'amélioration de la production de la biomasse et de réponse à la demande toujours plus grande de fourrages et de bois de chauffe. L'auteur aborde chacun de ces aspects, y compris l'utilisation des arbres et des arbustes et les besoins au plan de la recherche et de la vulgarisation.*

Resumen — *Los sistemas de agrosilvipastizales se han desarrrollado en respuesta a presiones de poblaciones humanas y animales junto con cambios de condiciones climáticas. Dichos sistemas, que integran los árboles o plantas leñosas y gramíneas con el cultivo del campo, garantizan la estabilidad de la productividad del suelo, logran una alta producción y variado rendimiento, mejoran la fertilidad del suelo y aumentan la provisión de forraje nutritivo a la ganadería en diversas condiciones agroecológicas. Comparados con los sistemas tradicionales de uso de la tierra, los sistemas de agrosilvipastizales tienen mucho mayor rendimiento y disponibilidad forrajera durante todo el año. Se han identificado, para situaciones específicas, los árboles forrajeros, especies de hierbas y sistemas de producción potenciales. Además de ser económicos, los sistemas dan por resultado mejoras ecológicas y se presentan como una gran promesa de acrecentamiento de la producción biomasiva y de* *satisfacción de la creciente demanda de forraje y leña. Este estudio trata cada uno de estos aspectos, inclusive el uso de árboles y arbustos y las necesidades de extensión e investigación.*

Introduction

India has a long history of shortages of animal feeds and fodders. The current gap between demand and supply is more than 50% (Singh 1987a). The problem has been the result of low productivity, ruthless exploitation of available grazing resources, preference by farmers of growing nonforage crops, and increasing animal population. To overcome this shortage, growing food and fodder crops on the same unit of land in rain-fed situations and integrating trees and grasses with crop farming on marginal and submarginal land with improved technology deserve high priority (Singh 1988a).

The concept

The concept of integrating farming and forestry originates from the realization that trees play a vital role in safeguarding the long-range interests of agriculture, including animal husbandry. Such integration, known as agroforestry, makes agricultural economy more viable. It involves more or less intimate and interacting associations of agricultural crops, horticultural crops, and woody perennials on the same unit of land. This form of land use has two main objectives:

- productivity, involving a multiplicity of outputs, and
- sustainability, which implies the conservation, or even improvement, of soils, broadening future land use options.

Generally, it is believed that such a system should not only integrate various crops for their complimentarity but should also conserve and improve productivity. Agroforestry embraces many production systems, such as agrosilviculture (crops, including tree and shrub crops), silvipastoral (pasture animals and trees) and agrosilvipastoral systems (crops, pasture animals, and trees) (Nair 1985), coppice farming, and horti–forage–food (fruit, forage, and food crops).

In India, where small land holdings, abundance of labour, and low input supply are characteristic, land sustainability should get priority over productivity and economical viability. However, because of the large number of the land owners, the low level of capital available, the inadequate research base, the lack of support service, and the complexity of knowledge required from the individual land owner, improvement in the system is comparatively slow. Elsewhere in the tropics, agroforestry systems also operate on small farms and barely within the cash economy (Briscoe 1983).

Tree leaves as livestock feed

Planting fodder trees to enhance livestock production and minimize seasonal nutritional deficits is becoming increasingly widespread in India. In hilly areas, feeding tree leaves to ruminant livestock is a traditional practice (Balraman 1980; Gupta 1981). In some parts of India, more animals feed on shrubs and tree fodders than on grasses and pasture.

Many tree leaves are used as ruminant feed in both the plains and the hills (Sen et al. 1978; Thakur et al. 1987). The comprehensive work of Gupta (1981) and others has indicated that several hundred varieties of tree fodder are commonly and traditionally fed to livestock in different parts of India; the feed value of many of these species needs to be studied properly. So far, only about 160 fodder tree leaves have been analyzed chemically; 40 of these are important in the livestock industry because of their wide distribution. Most tree leaves are rich in crude protein and calcium, and low in phosphorus and crude fibre.

Over 60% of the fodder requirements of goats are normally met with shrubs and tree fodders. Tree leaves and shrubs preferred by goats include peepal (*Ficus religiosa*), bargad (*Ficus benghalensis*), gular (*Ficus recemosa* or *Ficus glomerata*), neem (*Azadirachta indica*), jamun (*Engenia jambolans*), mahua (*Bassia latifolia*), jackfruit (*Artocarpus heterophylus*), bhimal (*Grewia oppositifolia*), kachnar (*Bauhinia variegata*), ber (*Zizyphus jujuba*), jherberi (*Zizyphus numularia*), mulberry (*Morus alba*), cassava (*Manihot esculenta*), gliricidia (*Gliricidia maculata*, *Gliricidia sepium*), babul (*Acacia arabica*), and khejri (*Prosopis cineraria*). Trees and shrubs such as *Acacia nilotica*, *Acacia tortilis*, *Albizia lebbek*, *Alianthus excelsa*, *Clerodendron phlomidis*, *Capparis zeylanica*, *Dichrostachys nutens*, *Gymnosporia spinosa*, *Leucaena leucocephala*, *Sesbania sesban*, and *Sesbania grandiflora* are also highly palatable and nutritious.

Trees can be grown on steep, rocky mountain slopes, in arid, saline, or water-logged soils, and in areas with severe climatic conditions. Also, trees do not need heavy inputs of fertilizer, irrigation, labour, pesticides, etc., as are generally needed to grow conventional fodder crops. Trees use and recycle nutrients that are beyond the reach of grasses and other herbaceous plants. Trees that accumulate nitrogen enhance forage quality. Their relative deep root system can exploit deep moisture resources and, using this and other strategies, trees are more tolerant to dry periods than pastures.

Research and extension is now being directed toward persistent, versatile trees and shrubs to ensure that conservative grazing management maintains a productive ecosystem and does not allow woody, unpalatable species to replace desirable fodders. Eradicating trees in humid and semi-arid areas enhances grass yields and animal production; however, in many situations, killing native trees is not necessary to improve animal production. In the arid zone, grass is often of better quality, stays green for much longer, and is more abundant under the shade of fodder trees, where potential evaporation is reduced by more than 50%. This has been observed with *Pennisetum pedicellatum* in the Sahel region of West Africa, *Panicum maximum* in Botswana and Queensland, *Cenchrus ciliaris* in Queensland (Wildin 1989), and *C. ciliaris* and *Cenchrus setigerus* in India (Gupta 1975). In such situations, unpalatable native trees of limited value should be replaced with others of greater intrinsic worth (e.g., species with palatable foliage or the capacity to fix nitrogen or produce timber).

Agrosilvipasture systems

In age-old "taungya" plantations, forest labourers grow agricultural crops with forest tree crops to meet daily requirements. This approach to production aims at obtaining food, fodder, and fuel from the same unit of land. Under rain-fed conditions, this can be achieved in a production system including the crop–grass–tree combination. Production increased threefold after legumes were introduced into the system (Table 1). Range legumes (*Stylosanthes hamata*) improved the cereal grass yield by 6–26% and contributed 6–16% toward total forage production (Singh 1988b). In addition to improving the nutritive value of grass, legumes provided an excellent ground cover, eliminating weeds and improving soil fertility.

Pasture production in silvipastoral systems is directly influenced by its establishment and management. Long-term studies on pasture production in association with fodder–fuel trees at the Indian Grassland and Fodder Research Institute, Jhansi, have revealed that, if properly established and managed, a pasture could be reasonably productive for 8 or 9 years. However, during the establishment year, pasture production is normally low, varying from 1.5 to 2.5 t/ha.

Deb Roy et al. (1978) studied the forage production of *Cenchrus ciliaris* and a mixture of *Chrysopogon fulvus* and *Sehima nervosum*, and the effect of different spacings of *Hardwickia binata* and *Albizia amara* on this production on typical red Bundelkhand soils. Forage production (4.23 t/ha) from the mixture of *C. fulvus* and *S. nervosum* was higher than that of *C. ciliaris* (3.74 t/ha). Forage production of *C. ciliaris* was affected by tree density, both under *H. binata* and *A. amara*; the mixture of *C. fulvus* and *S. nervosum* was relatively unaffected by tree density. In

Table 1. Production potential and energetics of restructured forage production systems.

Subecosystem	Maximum harvest (g/m²)	Annual energetics (kcal/m²)
Local situation		
Heteropogon contortus + Faveolatus	240	1 100.0
Reconstructed adaptable ecosystem		
Cenchrus ciliaris + Chrysopogon + Leucaena leucocephala + cowpea	670	3 697.5
C. ciliaris + Chrysopogon fulvus + Albizia lebbek + wild pigeon pea	790	3 357.5
Sehima nervosum + C. ciliaris + A. lebbek + Clitoria ternates	735	3 123.8
Setaria anceps + Brachiaria mutica + Sesbania grandiflora + Phaseolus calcaratus	590	2 507.5
C. ciliaris + A. procera + Phaseolus spp.	760	3 230.0
C. ciliaris + Prosopis juliflora + Dolichos lablab	710	3 017.5
C. fulvus + A. tortilis + D. lablab	515	2 188.8
A. lebbek + Heteropogon contortus	410	1 742.5

Source: Deb Roy et al. (1978).

the 5th year, with the development of a canopy, forage production was significantly reduced under both tree species. This was especially so in the case of *A. amara*, probably because of its inherent low branching and spreading crown. These results show the importance of opening the tree canopy through lopping or side pruning. In fact, *A. amara* has a high lopping potential for leaf fodder and firewood production.

Deb Roy et al. (1980) also studied the forage production of two grass species, (*C. ciliaris* and *C. setigerus*) and the effect of different spacings of *L. leucocephala* and *A. tortilis* on this production on typical red Bundelkhand soils. *Cenchrus ciliaris* had a higher forage production than *C. setigerus* (Table 2). *Cenchrus ciliaris* gave a peak forage production of 5.3 t/ha in closely spaced *L. leucocephala* and an overall annual mean forage production for 5 years of 4.3 t/ha.

Roy et al. (1984) reported a dry forage yield of 4.73 t/ha for *C. ciliaris*, 2.21 t/ha for *C. fulvus*, 3.92 t/ha for *Stylosanthes hamata*, and 1.57 t/ha for *Macroptilium artropurpureum* in association with *Dichrostachys cinerea* in a highly calcareous Bundelkhand wasteland. Deb Roy (1986a) reported higher pasture productions for *S. nervosum* (7.8 t/ha) and *C. fulvus* (7.4 t/ha) than for *C. ciliaris* (5.7 t/ha) in the 3rd year of establishment in association with *Albizia lebbek* on a typical Bundelkhand wasteland with a semirocky substratum. On the same site, in association with *Albizia procera*, a mixture of *C. ciliaris* and *Dolichos axillaris* gave peak forage production of 7.9 t/ha. Higher forage production from these systems was attributed to the better establishment and management of grasses. On similar sites, *C. ciliaris* in association with *Prosopis juliflora* (Israeli variety) gave a forage production of 6.0 t/ha, thereby disproving the notion that nothing grows under *P. juliflora*.

In association with *L. leucocephala*, *C. ciliaris* gave a forage production of 7.9 t/ha; *C. fulvus* produced 7.4 t/ha. In later years, *C. fulvus* outyielded *C. ciliaris*. On such sites, even after 7 or 8 years of establishment, *C. fulvus* and *C. ciliaris* produced forage at rates of 5.2 and 4.3 t/ha, respectively, in association with *D. cinerea* (introduced at year 4 with a density of 600 plants/ha). However, under the canopy of *A. lebbek*, these grasses gave lower forage productions: 4.1 and 3.2 t/ha, respectively.

The silvipastoral system, when compared with the traditional land-use system, yields seven times with year-round forage availability; forage that is both nutritious and high in protein (Singh 1988a) (Table 3). Promising shrub and tree species were

Table 2. Forage production (t dry matter/ha) in silvipastural systems.

Treatment[a]	1972	1973	1974	1975	1976	Mean
Ll, S_1, Cc	4.29	3.10	5.34	5.89	2.73	4.27
Ll, S_1, Cs	2.50	2.15	2.15	5.01	2.45	2.85
Ll, S_2, Cc	4.02	2.15	4.02	5.47	3.40	3.88
Ll, S_2, Cs	2.07	2.53	3.22	5.21	3.91	3.39
At, S_1, Cc	3.32	3.11	4.02	4.09	2.99	3.39
At, S_1, Cs	2.96	2.80	2.63	5.43	2.69	3.30
At, S_2, Cc	4.19	2.33	2.95	5.04	3.00	3.50
At, S_2, Cs	1.36	1.37	2.63	5.00	3.00	2.67
Mean	3.09	2.49	3.37	5.14	3.02	

Source: Deb Roy et al. (1980).

[a] Cc, *Cenchrus ciliaris*; Cs, *Cenchrus setigerus*; Ll, *Leucaena leucocephala*; At, *Acacia tortilis*; S_1, 4 × 4 m spacing; S_2, 4 × 6 m spacing.

Table 3. Production potential of some fodder trees in the Bundelkhand region of India.

Species	Age (years)	Trees/ha	Leaf fodder production (kg/tree)	Firewood (kg/tree)
Acacia tortilis	7	440	3.2	51.6
Albizia amara	7	440	13.5	86.6
Albizia lebbek	6	440	5.3	155.0
Albizia procera	6	440	11.3	85.5
Dichrostachys cinerea	6	440	0.8	13.6
Leucaena leucocephala	3	5000	0.8	5.5
	4	5000	1.9	11.9
Hawaiian Giant	1.5	5000	1.5	4.2
Sesbania grandiflora	3.5	5000	0.9	16.6
Sesbania sesban	3.5	5000	0.3	12.1

Source: Singh (1984).

tested on marginal and submarginal land sites with recommended plant densities for fodder and fuel. *Albizia* and *Acacia* species gave high firewood production; *Leucaena* and *Sesbania* produced the highest fodder yields per unit land. Because the growth habits of species differ markedly, a new avenue for combining different species on the same piece of land using appropriate planting geometry can enhance total firewood and fodder yields. Production under different silvipasture systems in the rocky conditions of the hill regions and in saline situations have also shown promise (Singh 1988c).

Prosopis cineraria, an unexploited resource of the Thar desert, India, is a tree of worship. Every plant part of this tree is used, providing fodder, fruit, firewood, timber, and construction and fencing materials. The canopy provides excellent shade, enhancing herbage yield, growth, and botanical composition of natural pastures. The highest herbage yields were observed with *Albizia lebbek* (113 t/ha) and *Tecomella undulata* (106 t/ha), followed by *Prosopis cineraria* (2.3 t/ha), *Prosopis juliflora* (0.8 t/ha), and *Acacia senegal* (0.8 t/ha) (Muthana et al. 1976; Ahuja et al. 1978). Sown pastures of *Cenchrus ciliaris* showed a gradual but significant decrease in plant height, tussock diameter, and herbage yield as the distance from the *Prosopis* trees increased.

Lopping management

Excessive, indiscriminate lopping of fodder trees has depleted valuable fodder resources, destroyed forest lands, and initiated soil erosion (Singh 1984). Long-term studies on lopping management of fodder trees at the Indian Grassland and Fodder Research Institute, Jhansi, have revealed that, if properly managed, considerable fodder and firewood may be obtained during lean periods without negatively affecting tree growth.

Deb Roy (1986b), while working on leaf fodder production of two *Albizia* species (*A. lebbek* and *A. procera*) grown in association with *Cenchrus–Stylosanthes* pasture, reported a higher leaf fodder yield in *A. procera*. The data was based on 2 years of lopping studies on 8- and 9-year-old plants. In *A. lebbek*, mean green and dry leaf fodder productions of 9.6 and 5.3 t/ha, respectively, were realized by lopping annually at one-third intensity; corresponding values were 6.2 and 2.8 t/ha with biennial lopping at two-thirds intensity. Roy and Deb Roy (1986) tried to standardize the lopping cycle of some tropical fodder trees between 5 and 10 years old, (*Acacia tortilis*, *Albizia amara*, *A. lebbek*, *A. procera*, *D. cinerea*, and *H. binata*). Based on 5-year data on various tree growth parameters as affected by lopping, fodder, and firewood yields and the response of trees to different lopping intensities and intervals, lopping treatments producing optimum, sustained yields have been identified (Table 4).

Except for *D. cinerea*, all species tolerated annual lopping. Five-year-old *D. cinerea* tolerated moderate loppings every 6-months, with an annual dry leaf fodder production of 2.1 kg/tree. This is equivalent to 1.3 t/ha with 640 trees/ha in a *Cenchrus–Chrysopogon* pasture. However, Roy et al. (1984) recorded a much lower leaf fodder yield (0.74 kg/tree) with similar age-group trees. This signifies the importance of lopping or browsing by animals to increase leaf fodder availability. *Albizia amara* and *A. procera* tolerated intense lopping; *A. lebbek*, however, could tolerate only moderate lopping. A fodder yield of 12.9 kg/tree (4.13 t/ha) was realized from 10-year-old *A. amara* trees with annual lopping at two-thirds intensity. With 7- to 8-year-old trees grown on a single-row plantation (5 m apart), a leaf fodder production of 5.96 t/ha was obtained. A much lower leaf fodder production of 3.62 kg/tree (1.81 t/ha) from a 14-year-old silvipastoral plantation was obtained by thinning the trees during the summer. In *A. amara*, more leaf fodder is available if lopping is done in the winters. An annual leaf fodder yield of 16.6 kg/tree was realized with *A. procera* with two-thirds lopping; *A. lebbek* yielded 4.0 kg/tree with one-third lopping.

Annual lopping of 8- to 10-year-old *A. tortilis* plantations resulted in 1.12 t/ha of dry leaf fodder; 7-year-old trees yielded 1.40 t/ha of dry fodder (Deb Roy et al. 1979). However, Roy and Deb Roy (1986), based on a long-term lopping trial of this species, recommended only one-third annual loppings for *A. tortilis*. This results in a lower fodder yield of 0.51 kg/tree. In the case of *H. binata*, an annual fodder yield of 3.67 kg/tree (1.17 t/ha) with one-third annual lopping was recorded. A similar production of 3.74 kg/tree (1.87 t/ha) of dry leaf fodder in silvipastoral plantations in association with *Sehima–Chrysopogon* pasture was also recorded. Roy and Deb Roy (1986) recorded a leaf fodder production of 10.2 kg/tree with biennial lopping of moderate-sized roadside plantations of *Bauhinia purpurea* grown 5 m apart.

Table 5 compares initial and lopped fodder yields, firewood yields, and crude

Table 4. Average annual fodder and fuel productions (kg/tree) of some tropical fodder trees under lopping management.

Species	Initial age (years)	Lopping treatment	Leaf fodder	Fuel
Acacia tortilis	10	1/3, annual	1.1 (0.5)	18.6 (11.2)
Albizia amara	10	2/3, annual	25.3 (12.9)	41.2 (23.6)
Albizia lebbek	6	1/3, annual	8.5 (4.0)	9.6 (5.1)
Albizia procera	6	2/3, annual	30.8 (16.6)	24.6 (14.6)
Dichrostachys cinerea	5	1/2, biannual	3.4 (2.1)	8.3 (5.1)
Hardwickia binata	10	1/3, annual	6.7 (3.7)	8.5 (5.5)

Note: Values in parentheses are dry weights (kg).
Source: Deb Roy (1986b).

protein contents of the leaf fodder. Except for *D. cinerea* and *H. binata*, average lopped yield is less than initial yield. Similarly, except for *A. tortilis* and *A. procera*, there is slight increase in the crude protein content of lopped leaves. Therefore, the fodder and firewood yields obtainable during lean periods, without negatively affecting tree growth, suggest that judicious lopping could be a profitable proposition.

Alley farming

In alley farming, fast-growing and coppicing trees are planted in hedgerows and the alleys are used for food, grain or forage production. Tree rows are lopped periodically and the loppings are used as forage or mulch under dryland conditions. Studies on *L. leucocephala* alleys (2 × 0.5 m) lopped at 1.5 m showed increased crop yields compared with the control. Besides regular crop production, such a system yields 6 t/ha per year of leaf fodder from leucaena and 7–9 t/ha of firewood at the end of a 3-year rotation. In *Acacia albida* alleys, Guinea grass yielded a maximum of 8 t/ha of dry forage; this was followed by nandi (*Setaria anceps*) and *C. ciliaris*. Row orientation of alleys has a very important role in the production of associated crops. "Angular" directions (northeast–southwest or southeast–northwest) are more beneficial to crop yields. Using leucaena leaves as manure increases the nitrogen content of the soil compared with basal or top-dressed chemical fertilizer. At 40 kg N/ha, leaf manure resulted in a yield 10% higher than that obtained using urea. In addition to these benefits, leucaena cultivation enriches the soil. The yield of the following cereal crop was 54% higher after the removal of 6-month-old leucaena compared with the control. For 1- and 2-year-old leucaena plantations, yield improvements were consistent for three crops.

Soil improvement

A chemical analysis of surface soil revealed that the organic carbon content and total phosphorus were highest under khejri (*P. cineraria*); nitrate nitrogen was also high (Aggrawal and Saxena 1975). Gupta (1975) found that soil moisture in a 120-cm soil profile was highest under khejri, followed by kumut, rohida, siras, and vilayti babul. Increased soil fertility is consistent with the nodulation in khejri (Basak and Goyal 1975). Singh and Lal (1969) also reported that the soil under khejri had higher contents of organic matter, total nitrogen, available phosphorus, and soluble calcium compared with the soil under babul (*Acacia nilotica* var. *indica*). Also, the pH value of the soil under khejri was near neutral (pH 7.3).

Recent investigations by Shankar and Saxena (1976) and Shankar et al. (1976) revealed that there was a gradual decrease in the percentage nitrogen and organic matter content of the surface soil (0–10 cm) as the distance from the khejri tree increased. This trend closely paralleled that observed for growth and production. High organic matter content in the soil under khejri may be due to leaf fall and its faster mineralization, perhaps because of the favourable moisture condition that exists under the khejri canopy (Gupta 1975). Potential species of trees, shrubs, and grasses and legumes for different agroecological and land situations have been identified (Singh 1988d).

Table 5. Average annual fodder and firewood yields (kg/tree) and crude protein (CP) contents (%) of some fodder trees with lopping management on wastelands.

Species	Initial age (years)	Initial			Lopped		
		Fodder	Firewood	CP	Fodder	Firewood	CP
Acacia tortilis	9	0.8	12.7	13.6	0.5	11.2	12.1
Albizia amara	9	18.3	37.7	18.6	12.9	23.9	19.1
Hardwickia binata	9	3.8	6.6	8.9	3.7	5.5	9.5
Albizia lebbek	6	4.6	8.0	27.1	4.2	5.1	26.0
Albizia procera	6	17.9	17.4	18.7	16.6	14.6	16.7
Dichrostachys cinerea	6	2.8	8.6	12.9	3.9	9.3	13.9

Source: Roy and Deb Roy (1986).

Precautions

The quality of any green fodder mainly depends on the voluntary intake and availability of protein, energy, minerals, and vitamins. Although information on the palatability of fodder tree leaves is scanty, it is known that dry matter intake varies from 1.0 to 2.5 kg/100 kg body weight. This low dry matter intake thus appears to be a limiting factor in energy supply from tree leaves. About 60% of fodder tree leaves evaluated contain less than 50% total digestible nutrients (TDN) on a dry matter basis; 40% of tree leaves contained more than 50% TDN. Thus, the available energy (TDN) in tree leaves is low. Tree fodders like *Adina cordifolia*, *Aegle marmelos*, *Alianthus excelsa*, *Bauhinia variegata*, *Ethretia laevis*, *Ficus hookerii*, *Grewia optiva*, *Helisteres isora*, *Holoptelia integrifolia*, *Lanrea coromandalica*, *Leucaena leucocephala*, *Moringa oleifera*, and *Morus alba* contain more than 55% TDN and are, thus, a better energy source.

The low digestibility of many tree leaves is possibly due to their high lignin and tannin contents. Tannins also bind proteins and thereby lower their digestibility. In addition, tannins adversely affect calcium use. The structure of crude fibre, which in tree species is complex and considerably lignified, negatively affects the digestibility of other nutrients (Patnayak 1982). Some tree leaves also contain toxic constituents. For example, the high mimosine content of *L. leucocephala* is toxic to both ruminants and nonruminants. *Stranvaesia nussia* leaves contain HCN. *Taxus baccata* leaves can be deadly if consumed in large enough quantities. *Ficus nemoralis* leaves cause haematuria when they are fed to cattle.

Economics

An economic evaluation of the silvipastoral system needs to analyze the system's efficiency compared with that of a rain-fed farming system. Whereas rain-fed farming in most of the semi-arid and arid tropics embraces only seasonal grain, oilseed, and pulse crops, silvipastoral systems are based on perennial plants. A study conducted at the Indian Grassland and Fodder Research Institute, Jhansi, showed that, at the peak production of rain-fed cropping, the net gain is 86.5% of that obtained in the natural grass and tree system (trees lopped twice a year). However, in poor-rainfall years, the crops suffer, and production could be halved. The efficiency of an improved silvipastoral system is expected to be 5.3 times that of natural grazing lands or 1.8 times that of the best rain-fed system (Singh 1987b). In terms of input and output, efficiency would still be higher because rain-fed farming involves expenditures for cultivation, seed, fertilizers, and labour every year; in the silvipastoral system these inputs are experienced only once, in the 1st year. Productivity enhancement is mainly due to the trapping of solar energy at two tiers: the canopies of both woody and herbaceous plants.

Prajapati (1979) calculated the yields of various components in a fuel–fodder plantation under ravine conditions. Dutta (1979) studied the economic aspects of a three-tier system incorporating the concepts of silvi- and horti-pastoral production in the northeastern region of India and concluded it to be an economically viable and socially acceptable alternative to "jhuming." The economics of silvipastoral systems have been studied in detail in the hot, arid regions of Rajasthan (Gupta 1983). He estimated net annual returns from silvipastoral systems at 360 to

3 270 INR/ha, depending on the species and felling cycles and using a discount rate of 11% (in July 1989, 15 Indian rupees [INR] = 1 United States dollar [USD]). Compared with this system, the returns from annual crops were 180 INR, 20 INR, including the cost of family labour, and 6.5 INR, including the return from existing trees and bushes. Gupta (1983) concluded that multiple-use silvipastoral systems are economically attractive and ecologically beneficial.

Singh and Pathak (1986) observed a net profit of 1 830 INR/ha over 3 years from intensive pasture development under tree plantations. These benefits are optimized under controlled grazing after the 3rd year. In a cut-and-carry system, however, net returns are lower. Singh and Pathak (1986) also observed that cost could be minimized with a relatively larger land area, legume introduction, and farming system approach. Considering the problems of wastelands, this approach includes development, land conservation, and soil amelioration.

Research and extension needs

Research on fodder and fuel trees beneficial to an agrosilvipastoral system should emphasize the following areas:

- introduction, testing, improvement, and multiplication of multipurpose tree species under different agroecological situations;
- selection of seeds of trees and grasses from natural forests and rural areas;
- soil productivity status with respect to various species and management and its impact on soil structure and nutrient supply;
- secondary productivity involving grazing, stall feeding, and feed supplementation, transforming the forage production data into animal production data per unit land;
- physiological studies, such as tolerance to salt and drought, transpiration rate and photosynthetic activities;
- lopping, harvesting, and coppicing management;
- postharvest management studies, such as transporting, drying, storage, and processing of forestry products;
- economic environment and its impact on system components and other farming systems; and
- socioeconomic aspects, including marketability of the product and its impact on rural prosperity.

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Availability and use of shrubs and tree fodders in India

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Abstract — *Ruminants feed widely on shrubs and tree leaves rather than on grass or grass legume pastures in India. Some tree fodders are almost as nutritious as leguminous fodders. Data is presented on nutritional aspects of tree leaves and their patterns of use by animal species. The data suggest the necessity for integrated, intensive efforts to cultivate and propagate shrubs and tree leaves. The critical limitations and constraints to use require, however, more intensive research for economic feeding. Government policies concerning the production of these feeds require an integrated approach involving scientists and government departments concerned with fodder tree production for animals.*

Résumé — *En Inde, les ruminants se nourrissent plus généralement de feuilles d'arbustes et d'arbres que de graminées et de légumineuses. Certains arbres fourragers sont presque aussi nutritifs que les légumineuses. L'auteur présente des données sur les aspects nutritionnels des feuilles d'arbre et sur l'utilisation de ces feuilles par les espèces animales. Les données indiquent la nécessité d'efforts intégrés et intenses pour cultiver et propager l'utilisation de feuilles d'arbustes et d'arbres. Les limites et les obstacles critiques à leur emploi exigent toutefois l'exécution de recherches intenses sur l'alimentation économique des animaux. Les politiques gouvernementales relatives à la production de ces fourrages exigent, elles, une approche intégrée dont seraient les scientifiques et les ministères gouvernementaux s'intéressant à la production d'arbres fourragers pour les animaux.*

Resumen — *En la India, los rumiantes se alimentan en gran medida de hojas de arbustos y árboles antes que de gramíneas o hierbas leguminosas. Algunos forrajes de árboles son casi tan nutritivos como los forrajes de leguminosas. Se brinda información sobre los aspectos nutritivos de las hojas de árboles y las formas en que las utilizan las especies animales. Los datos sugieren la necesidad de hacer esfuerzos integrdos e intensivos para cultivar y multiplicar hojas de arbustos y árboles. Sin embargo, las limitaciones y restricciones decisivas de su uso requieren una investigación más exhaustiva para encontrar una alimentación económica. Las políticas gubernamentales con respecto a la producción de estos alimentos exigen un método integrado que involucre a científicos y departamentos del gobierno ocupados en la producción de árboles forrajeros para animales.*

Introduction

In India, there is a huge annual shortage of concentrates (44%), green fodders (36%), and dry roughages (36%) for animal feeds. This situation is caused by periodical rainfall, confined to the monsoon season. These estimates do not, however, include feed resources from shrubs and tree leaves. Tree leaves are commonly referred to as "top feeds" and are often considered as emergency livestock fodder; they contribute to the staple feeds of small and large ruminants in India. These feeds are particularly valuable for goats, whose population in India ranks first in the world. For this species, shrubs and tree fodders contribute more than 60% of total feed.

Value of shrubs and tree leaves

In many parts of India, more animals feed on shrubs and trees than on surface fodders like grasses and grass–legume pastures. The leaves are useful as protein supplements to straws and other low-protein fodders. Dry, deciduous vegetation is mostly found in semi-arid regions and is confined to the northwest area of the Indian subcontinent. In this complex of vegetation, trees predominate and shrubs form the important second or third tier of the stand. Tropical thorn forests are also found and are spread throughout the arid and semi-arid regions of India. The southern regions have a more gravelly stratum, where the shrubs are sparse in comparison to the north.

In hilly areas, livestock are maintained mostly on tree loppings. Generally, the dry matter content of the various tree leaves varies from 20 to 40%, with 10–15% crude protein on a dry matter basis (Singh 1982). Higher values of between 20 and 23% have been recorded for leucaena (*Leucaena leucocephala*) or Su-babul (Upadhyay et al. 1974) (Table 1). The ether extract fraction is also fairly high compared with annual and perennial, natural and cultivated grasses and hays. Tree leaves contain comparatively low percentage of crude fibre compared with grasses and hays. Their fibre is complex and highly lignified at maturity. The crude protein content decreases and the crude fibre content increases with increasing age of the tree leaves (Singh 1981).

Calcium content of tree leaves is 2–3 times more than that of cultivated fodders or grasses. The phosphorus content is, in general, low, resulting in a wide calcium to phosphorus ratio (Table 1). There is a variation in tannin content, which appears to be a limiting factor in the feeding value of some tree leaves (Lohan et al. 1980). The presence of tannins has been found to adversely affect the dry matter digestibility and use of nutrients, and an inverse relationship exists between tannin content and crude protein digestibility (Lohan et al. 1980). It has also been observed that the palatability, digestibility, and nutritive value (Table 2) of tree leaves decreases (Negi 1977) as the leaves advance in maturity (Table 3).

The palatability, digestibility, and nutritive value of tree leaves are higher with goats than with sheep (Bohra 1980). Although the intakes of nitrogen and calcium are higher, their balances are poor. Phosphorus balances are negative or marginally positive in most cases because the tree leaves are low in phosphorus. The higher calcium content of tree leaves is of no value without phosphorus supplementation when feeding sheep and goats (Singh 1981).

Table 1. Proximate composition of some fodder tree leaves (% dry matter).

Species	Common name	Crude protein	Ether extract	Crude fibre	Nitrogen-free extract	Calcium	Phosphorus	Source
Alianthus excelsa	Ardu	19.56	3.68	13.52	47.74	2.42	0.17	Singh and Patnayak (1981)
Acacia arabica	Babul	10.95	8.97	13.75	58.03	1.21	0.06	Prasad et al. (1974)
Celtis tetrenda	Kharik	14.00	4.05	16.60	44.00	4.08	0.13	Joshi and Ludri (1966)
Ficus roxbergis	Timla	13.35	4.65	7.71	64.87	1.31	0.17	Joshi and Ludri (1966)
Grewia elastica	Dhaman	19.87	9.50	11.20	47.41	2.74	0.05	Khajuria and Singh (1967)
Gymnosporia spinosa	Kankera	9.43	3.59	15.33	59.83	3.92	0.13	Mohan et al. (1977)
Leucaena leucocephala	Su-babul	21.45	6.54	14.25	49.48	2.70	0.17	Upadhyaya et al. (1974)
Prosopis cineraria	Khejri	13.98	1.88	17.80	43.44	2.73	0.15	Singh (1981)
Zizyphus nummularia	Pala	14.06	2.96	17.04	55.85	2.79	0.14	Malik and Nath (1970)

Table 2. Dry matter intake (DMI), digestible crude protein (DCP), and total digestible nutrients (TDN) of some fodder tree leaves (% dry matter).

Species	Common name	DMI/100 kg body weight	DCP	TDN	Source
Alianthus excelsa	Ardu	3.80	16.24	63.80	Singh and Patnayak (1977)
Celtis tetrenda	Kharik	4.10	9.21	40.48	Joshi and Ludri (1966)
Dendrocalamus strictus	Bamboo	2.51	9.34	48.91	Kehar and Goswami (1956)
Ficus glomerata	Gular	—	6.69	53.82	Majumdar et al. (1967)
Ficus roxbergis	Timla	1.87	6.21	57.30	Joshi and Ludri (1966)
Grewia elastica	Dhaman	3.50	15.52	71.30	Khajuria and Singh (1967)
Gymnosporia spinosa	Kankera	3.71	2.66	33.16	Mohan et al. (1977)
Leucaena leucocephala	Su-babul	4.00	16.73	70.22	Upadhyaya et al. (1974)
Morus alba	Tut	3.44	10.68	59.59	Kehar and Goswami (1956)
Prosopis cineraria	Khejri	2.18	4.49	40.99	Bhandari et al. (1979)
Zizyphus nummularia	Pala	2.05	5.56	49.70	Nath et al. (1969)

Table 3. Leaf tannin content and its relation to nutritive value.

Species	Stage	Tannin (% DM)	DM (% D)	% DM	% D	DCP (% DM)	TDN (% DM)
Grewia optiva	Early	0.0	58	20.8	76	15.8	55.2
	Late	0.0	55	20.2	67	13.6	52.3
Robinia pseudocacia	Early	2.7	41	25.1	39	9.8	38.5
	Late	1.5	48	20.6	56	11.5	42.8
Bauhinia variegata	Early	2.1	35	15.8	43	6.8	35.5
	Late	1.2	48	14.0	56	7.9	45.5
Dendrocalamus hamiltonii	Early	0.6	44	15.1	68	10.3	36.9
	Late	0.1	55	14.2	76	10.8	48.5

Note: D, digestibility; DM, dry matter; DCP, digestible crude protein; TDN, total digestible nutrients.
Source: Negi (1977).

On average, the digestibility coefficients of shrubs and tree fodders in ruminants were of about 66% for dry matter, 81% for crude protein, 35% for ether extract, 32% for crude fibre, and 78% for nitrogen-free extract for green leaves. The digestibility coefficients for crude protein, crude fibre, and ether extract were higher with dry leaves because of their lower dry matter content.

Patterns of use by animals

Fodder trees currently provide concentrates to the livestock population of both the sedentary, marginal and the nomadic farmers. The landless population who own small herds of sheep and goats depend on shrubs and tree feed resources growing near the village, roadsides, and on community lands. The trees provide valuable feeds at low cost and are easily accessible. When the sources in the vicinity of the villages are depleted, the rural women frequent reserve forest areas, sometimes walking 10–15 km in the hills to meet the daily requirements of ruminants.

The fodder trees throughout the country are lopped by local people depending on requirements for feeding. Whereas sheep prefer to graze close to the ground, goats browse on a wide variety of shrubs and lower branches of trees, leaving the upper branches for camels. Thus, these species do not compete with each other in grazing. Sheep and goats are fed loppings when the surface vegetation, including shrubs, becomes scarce, especially during the winter and summer months. Grazing management generally involves browsing by sheep and goats on waste grasses and shrubs and the feeding of fresh, lopped tree leaves. In almost all feeding experiments on shrubs and tree leaves conducted throughout India (Malik and Nath 1970; Singh and Bhatia 1982; Verma et al. 1982; Mali et al. 1984), goats used green leaves most efficiently followed by sheep, camels, and cattle.

It is also a common practice throughout India to lop and dry tree leaves when they are abundant and store them for feeding during periods when feeds are scarce. Generally, green leaves and branches are lopped, piled into a heap, and dried in the field. The leaves are separated from the twigs and branches after drying and are stored. Some of the dry leaves have also been successfully incorporated in concentrate supplements and feed-lot diets for sheep and goats.

Performance and economics

Singh (1981) compared the use of *Zizyphus nummularia* (Pala) leaves in adult sheep and goats and observed that the dry matter intakes in goats were almost double those in sheep and that the digestibility coefficients of dry matter, crude protein, ether extract and crude fibre were higher in goats than in sheep (Table 4). Bohra (1980) obtained similar results in sheep and goats fed *Prosopis cineraria*. The superior digestive efficiency, especially of crude fibre, in goats can be attributed to their slower rate of passage of digesta.

The performance of lambs and kids fed *P. cineraria* (khejri) (Singh and Bhatia 1982) revealed that kids gained and lambs lost weight under identical management conditions (Table 5). It is fairly well-established that tree leaves, when fed alone, cannot support growth although they contain 13–20% protein. They have been

Table 4. Use of *Zizyphus nummularia* by sheep and goats.

	Sheep	Goats
Intake		
Dry matter intake (g/day)	632	1 103
Dry matter intake per 100 kg body weight	2.1	3.3
Dry matter intake/kg$^{0.75}$ (g)	41.0	78.6
Digestible crude protein (g)	27.2	61.9
Total digestible nutrients (g)	311.4	531.7
Digestibility (%)		
Dry matter	41.1	45.7
Crude protein	35.6	47.8
Ether extract	20.9	35.2
Crude fibre	33.6	51.8
Nitrogen-free extract	62.2	51.9

Source: Singh (1981).

successfully incorporated into the concentrate supplements and feed-lot diets of sheep and goats because digestibility is low (20–40%). *Prosopis cineraria* leaves and concentrate mixed at 20:80 for lambs (Bhatia et al. 1976) and 50:50 for kids (Parthasarathy 1986) gave maximum growth rates of 80 and 100 g, respectively (Table 5). Tree leaves, either green or dried, when fed along with concentrates, become a valuable feed resource for small ruminants.

The pods of many fodder trees have been tested as a feed resource for sheep, goats, and cattle. *Acacia* pods are commonly fed to sheep and goats by shepherds. Likewise, pods of *Prosopis juliflora*, either green or dried, are extensively fed to sheep and goats by farmers. Gujarathi et al. (1981) studied the use of *Prosopis juliflora* in the maintenance diets of bullocks. Powdered pods have been incorporated into concentrate mixtures and pelleted feeds for sheep at a rate of up to 20% (Reddy and Reddy 1985).

During the last three decades, extensive work has been carried out to determine the nutritive value of various tree leaves; however, the economic aspects of feeding tree leaves to livestock still needs to be investigated. The costs of collecting dried leaves, processing, and weight gain and milk production should be assessed when these materials are incorporated into diets. Singh et al. (1980) estimated the cost of collecting *Alianthus excelsa* (ardu) leaves to be 15 INR/q (1 q = 100 kg) and the authors observed that cross-bred rams gained 150 g/day when fed ardu leaves with a dry matter intake of 1.8 kg (in July 1989, 15 Indian rupees [INR] = 1 United States dollar [USD]). The feed cost per kilogram weight is 2 INR, which is highly economical. In fact, this is exactly how the shepherds raise goats in India, with minimal feed cost. Shukla (1982) calculated the cost of milk production by incorporating powdered *P. juliflora* pods at 15% in the concentrate mixture and babul (*Acacia nilotica*) seed pods at 15%, and observed that feed cost per kilogram of milk was reduced by 10%.

Cultivation and propagation

Tree fodders are primarily for fuel; however, their value for feeding ruminants necessitates the planting of multipurpose fodder trees. The need to introduce exotic

Table 5. Results of four studies on the performance of kids and lambs fed shrubs and tree leaves.

Study	Feeding regime	Duration (days)	Intake (g/day)	Growth rate (g/day)
Singh and Bhatia (1982)				
Kids	Khejri leaves	50	672	46
Lambs	Khejri leaves	50	539	–28
Bhatia et al. (1976) (lambs)	Concentrates	35	268	89
	80% concentrates + 20% neem leaves	35	268	66
	80% concentrates + 20% khejri leaves	36	225	80
Parthasarathy (1986) (kids)	Khejri leaves	90	638	18
	25% concentrates + 75% khejri leaves	90	779	81
	50% concentrates + 50% khejri leaves	90	732	100
	75% concentrates + 25% khejri leaves	90	619	94
Bhatia and Ratan (1981) (lambs)	20% concentrates + 80% pala	90	548	–3[a]
	50% concentrates + 50% pala	90	654	24
	80% concentrates + 20% pala	90	648	37

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[a] In 2 months, three of six lambs died under this regime.

and indigenous fodder trees in a particular region arises either because the area lacks such useful shrubs and trees, or because such species are slow in growth and unable to meet requirements (Patil et al. 1983). A large number of exotic and indigenous trees including fodder trees were introduced to the Central Arid Zone Research Institute, Jodhpur, during the 1950s. The most promising amongst the exotic fodder trees and shrubs are *Acacia tortilis*, *Cellophospermum mopane*, *P. juliflora*, *Dichrostachys mutans*, *Brasilettia mollis*, *Pittosporum phillyraesides*, *Schirueus mole*, *Atriplex* spp., and *Zizyphus spinacristi*. Among the successful indigenous introductions are *Albizia amara*, *Cardio roti*, *Albizia lebbek*, *Acacia nilotica*, *Hardwickia binata*, *Azardirachta indica*, *A. excelsa*, and *P. cineraria*.

During the 1970s, many exotic and indigenous fodder trees and shrubs were introduced by the Indian Grassland and Fodder Research Institute in Jhansi. The most promising exotic species are *L. leucocephala*, *A. tortilis*, *D. mutans*, and *C. mopane*. The promising indigenous introductions are *A. amara*, *H. binata*, *A. lebbek*, *Sesbiana sesbum*, *A. nilotica*, *Dalbergia sissoo*, *A. indica*, and *Albizia procera*. The first two species, *A. amara* and *H. binata*, have been introduced successfully into semi-arid areas (Deb Roy et al. 1980). Some of these species have also been successfully propagated in silvipastoral and agroforestry systems (Patil et al. 1979; Pathak et al. 1981).

Species suitable for various regions

It is difficult to select fodder species based only on climate; soil factors are equally important. However, an attempt was made to broadly select fodder tree species suitable for the various climates of India. Deb Roy and Pathak (1975) listed important shrubs and trees suitable for the five agroclimatic regions of India.

Propagation of fodder trees in integrated systems

Few attempts have been made to plant trees for fodder. Some systematic work on the propagation of fodder trees and shrubs was done at the Indian Grassland and Fodder Research Institute during the 1970s in various integrated systems. The Central Arid Zone Research Institute in Jodhpur has done commendable work on the cultivation of trees and shrubs for the stabilization of sand dunes and other arid habitats. In addition, techniques for the propagation of arid tracts have been standardized (Bhimaya and Choudhury 1961; Kaul and Nambiar 1966).

Silvipastoral system

Ideal trees and shrubs for a silvipastoral system are those that

- are compatible and have a complimentary effect on grasses and legumes,
- have long tap root systems with little superficial roots,
- are drought and frost hardy,
- have little or no allelopathic effect on the pasture,
- are leguminous with a light canopy during the monsoon season, and
- are resistant to pest and diseases common to pasture grasses and legumes.

Cultivation of some of the tree fodders in association with grasses and grass–legume mixtures has been standardized by Deb Roy and Pathak (1975). Deb Roy et al. (1980) detailed the technique and the performance of various fodder trees in association with grasses and grass–legume mixtures. The pasture remains green for a greater period than in the open and the grass is more nutritious. Growing heifers grazing in the silvipastoral system can maintain their body weight, even during the dry summer period, if 2 kg tree leaves is provided without any concentrates or mineral mixtures.

Forestry systems

Ideal trees and shrubs for forestry systems are those that

- have a canopy that allows more light on the ground for crop growth,
- show more leaf production during the dry periods and less leaf production during crop growth,
- have leaf litters of little allelopathic potential and quick mineralizing nature,
- have strong tap root systems with less side roots,
- are resistant to pests and diseases common to crops,
- respond quickly to irrigation and fertilization, and
- have nitrogen-fixing properties.

In agroforestry systems, some of the fast-growing fodder trees and shrubs, such as *L. leucocephala*, *Sesbiana grandiflora*, and *Sesbania sesban*, could be propagated in association with fodder and cash crops without jeopardizing their production. In farm forestry systems, fodder trees such as *L. leucocephala*, *S. grandiflora*, *Morus alba*, and *S. sesban*, were successfully cultivated along farm roads, boundaries, canal banks and riversides. Besides providing nutritious green fodder, the system produces firewood within 4 years and a coppice rotation of 3 years. The system also protects the canal and river banks from erosion. In both these systems, the soils become enriched in nitrogen, phosphorus, carbon, and sulphur over a few years despite the annual harvest of forage.

Critical limitations and constraints

Most fodder tree species are under stress because of unplanned defoliation. Socioeconomic conditions and religious beliefs in India are such that the reduction of unproductive cattle is a major constraint for formulating any well-planned policy for the systematic production and use of tree foliage. No special, systematic attention has been given to the establishment and propagation of fodder tree species; the common belief is that such resources are plentiful, which is far from truth. The Indian Department of Forestry is primarily interested in raising economically important species. The village forests today are not in good condition and, in many situations, the topsoil is being washed away, exposing rocks and losing productive capacity. These lands today are exercise grounds for the village livestock.

Some of the other constraints are the concept of land being everybody's property but nobody's responsibility and the multiple control over community lands with undemarcated rights of the villagers and the use of community lands. The lack of peoples' participation and unrealistic goals and targets for the plantation of community lands are further constraints. The proposal for land-use legislation does not appear to provide a solution because theories and practices whose validity has been proved cannot be forced on people.

Toxicity problems

Two toxic factors commonly found in tree fodders are tannic acid and mimosine. Tannic acid affects protein metabolism (Badaway et al. 1969; Lohan et al. 1980); mimosine, an uncommon amino acid present in the leaves of leucaena, causes ill effects when ingested in large doses (Hamilton et al. 1968). Some trace minerals, such as fluorine, molybdenum, and selenium, are reported to be present in toxic amounts in some tree leaves (Gupta et al. 1982; Prasad 1982). There are also some tree leaves in the hilly areas of Uttar Pradesh, Kashmir, and Assam that are deficient in copper and zinc (Sawhney et al. 1977).

Tannins are widely distributed in plants and adversely affect the digestibility of dry matter and the use of nutrients. There is a wide variation in leaf tannin content in different tree species. Lohan et al. (1980) reported the tannin content of tree fodders in Himachal Pradesh. Negi (1977) observed that the level of tannins was higher in the early stages of growth (see Table 3) and that the higher content of tannin inhibited nutritive value. Generally, the nutritive value of tree leaves should decline with increased maturity (Majumdar et al. 1967); however, only *G. optiva*, with no tannins, showed such a trend. In others, higher levels of tannins depressed the digestibility of both dry matter and crude protein because of their inhibition of proteolytic and cellulolytic enzymes (Lyford et al. 1967).

In general, it appears that the primary effect of tannins is on protein digestibility and not on the digestibility crude fibre, nitrogen-free extract, or ether extract. In view of the highly deleterious role of condensed tannins, Lohan et al. (1983) partitioned the total tannins into condensed and hydrolyzable forms. Tree fodders free of condensed tannins appear to be used better than those with condensed tannins. The crude fibre digestibility of tree fodders free of condensed tannins ranged from 63 to 79%; in tree fodders containing a high level of condensed tannins (*E. jambolana*, 3.23%; *T. bellirica*, 5.20%), the digestibilities were 1 and 10%, respectively. Moderate intakes of tree fodders containing tannins do not seem to affect palatability or digestibility of nutrients, except for a slight decrease in crude protein intake.

Extensive studies are needed to determine condensed and hydrolyzable proportions of tannins in important tannin-containing tree fodders. Levels of tolerance to tannins by livestock and the effects of tannins on microbes in the rumen should also be investigated.

Government policy

The National Commission on Agriculture (NCA 1976) received a communication from the Government of India recommending that the Indian

Veterinary Research Institute, National Dairy Research Institute, and agricultural universities undertake studies on the nutritive value of tree fodders, realizing the importance of farm forestry and social forestry in rural development programs. The World Bank is prepared to finance such social forestry projects.

Together with changes in livestock populations, there is also the changing lifestyles of the human population and the agronomic practices in different agroclimatic zones. Under these circumstances, the proliferation and use of fodder trees and forages have to be controlled so as not to disturb the ecological balance. The economic benefits of fodder trees can then be realized through livestock. Observing the ecological degradation, the Government of India has made it a policy to reverse the ecological degradation by way of afforestation. *Vanamohotsava*, for example, is an annual celebration in July that focuses on intensive tree planting. Specifically, multipurpose species are planted to provide the basic "five F's" (fuel, fodder, fibre, fruit, and fertilizer). The existing programs in social forestry envisage augmentation of village income by producing fuel, fodder, food, fibre, fertilizer, and forest products for plant-based industries (oil, rubber, etc.). This new policy aims at the rehabilitation of land resources for future use and the reduction of pressure on the reserve forest.

How to increase top feed use and efficiency

An integrated approach for the restoration and benefit of the community needs to be adopted for temperate, tropical, and semi-arid fodder trees. Attention must be focused on the following aspects while formulating government policies for various integrated systems:

- Promising trees and shrubs for introduction into the various climatic zones of India must be identified, with simultaneous development of easy and quick methods of raising suggested fodder trees under various integrated systems.
- A rational proportion of tree and shrub cover in grazing lands needs to be developed.
- An efficient marketing network is needed to accelerate the judicious use and to set proper prices for minor products.
- The two-tier concept, providing forage to the animal population and increasing the carrying capacity of the grazing lands, must be promoted. The heterogeneity ensures better use of environmental resources as the biomorphs are of different heights and their roots extend to different depths.
- A diversified or multitiered silvipasture system, that will ensure better use of solar energy, capture efficiency, and energy flow to the food chain, should be developed.
- People's involvement for proper restoration of fodder trees should be sought while afforesting community lands.
- The *Van Panchayats* (community tree plantations in villages) need to be administered by a single department and a village committee should decide on the areas to be used, the species to be planted, and on the protection and

maturity of plants. Enough fodder should be available within a 7 km walking distance.

- There should be a complete ban on the industrial use of fodder trees.
- The principle of shrubs and fodder tree management should sustain supplies of fodders together with rest periods to ensure recovery from any damage caused by partial defoliation.
- Lopping management varies from species to species depending on their growth capacity after lopping, their active growing period, their period of leaf fall, etc. However, the following guidelines can be kept in mind about their management: fresh leaves should not be lopped as they are often toxic; saplings and poles should not be lopped; about two seasons' rest is required after lopping for recovery; lopping may be restricted to the lower two-thirds of the crown, the upper one-third can produce the feed; at the time of lopping, branches having a diameter of over 7.5 cm should be avoided; and lopping should be avoided as much as possible on eroded areas or on areas prone to erosion.
- The incorporation rate of tree leaves and pods into the diets of different livestock, without loss of animal performance, should be determined.
- Large-scale production of complete pelleted feeds for sheep and goats should be attempted by incorporating different tree leaves and pods that have fallen to the ground.
- The chemical composition of leaves and pods, nutritive values, and toxic factors and the methods to remove them need to be studied.
- The economic feasibility of incorporating fodder leaves and pods into livestock diets needs to be determined.

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Availability and use of shrubs and tree fodders in Nepal

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Abstract *— Fodders from more than 100 different kinds of trees and shrubs are used as animal feed in Nepal. They supply about 28% of* 5.85×10^6 *t total digestible nutrients (TDN). More than 75% of these trees and shrubs are used from November to June. Species of the high hills take 5–10 years and those of the hills 3–10 years to produce, with their fodder yield ranging from 20 to 400 kg/year. This depends on species, locality (climate × soil), age, season, and method of lopping. Most of the fodder trees and shrubs in Nepal supply firewood, timber, fruits, vegetables, fibre, and soap/fat, and are used for agricultural tools, in medicine, and as live hedges. Fodder trees and shrubs are usually lopped once a year and fed fresh to the animals. These plants are either privately owned or are forest trees. There are two distinct groups: shrubs/bushes or small trees, usually for sheep and goats, and large trees, for cattle and buffaloes. Some species are known to increase or decrease milk yield and milk fat yield. Others cause dysphagia, hematuria, and urinary problems. In general, these species are rich in crude protein, ranging from 7.8 to 18.8%. Their dry matter content ranges from 40 to 50%.*

Résumé *— Au Népal des fourrages provenant de plus d'une centaine d'arbres et d'arbustes différents servent à l'alimentation des animaux. Ils fournissent environ 28 % des* $5,85 \times 10^6$ *t des nutrients digestibles (TND). Plus de 75 % de ces arbres et arbustes sont utilisés de novembre à juin. Les espèces des hautes collines prennent de 5 à 10 ans à produire, tandis que celles des collines prennent de 3 à 10 ans. Leur rendement en fourrage va de 20 à 400 kg/année. Ce rendement dépend de l'espèce, de son emplacement (climat et sol), de son âge, de la saison et de la méthode d'émondage. Presque tous les arbres et arbustes fourragers du Népal fournissent du bois de chauffe, du bois d'oeuvre, des fruits, des légumes, des fibres, du savon/graisse, sans compter leur utilisation dans la fabrication d'outils aratoires, en médecine et comme haies vives. Les arbres et arbustes fourragers sont habituellement émondés une fois par année et les parties émondées données fraîches à manger aux animaux. Ces plantes sont propriété privée ou des arbres des forêts. Elles sont divisées en deux groupes distincts : les arbustes ou petits arbres, normalement réservés aux moutons et aux chèvres, et les grands arbres qui sont réservés aux bovins et aux buffles. On sait que certaines espèces augmentent ou diminuent la production de lait et la matière grasse du lait. D'autres causent la dysphagie, l'hématurie et des problèmes urinaires. En général, ces espèces sont riches en protéine brute, dont la teneur varie de 7,8 à 18,8 %. Quant à leur teneur en matières sèches, elle va de 40 à 50 %.*

Resumen *— En Nepal, se utiliza el forraje de ms de 100 tipos diferentes de árboles y arbustos como pienso o alimento animal. Proveen aproximadamente 28% de* $5,85 \times 10^6$ *t de nutrientes totalmente digeribles (TDN). Más del 75% de* *estos árboles y arbustos se utilizan desde noviembre a junio. Las especies de las montañas requieren, para tener productividad, de 5 a 10 años y las de las colinas de 3 a 10 años, con una producción de forraje que varía de 20 a 400 kg/año. Esto dependerá de las especies, situación (clima y suelo), edad, estación y método de poda. En Nepal, la mayoría de los árboles y arbustos para forraje suministran leña, madera, frutas, vegetales, fibra y grasa saponificable, y se utilizan para hacer implementos agrícolas, en medicina y como setos vivos. Usualmente, los arbustos y árboles forrajeros se podan una vez por año y se dan frescos a los animales. Estos árboles se encuentran en propiedades privadas o en bosques públicos. Hay dos grupos distintos: arbustos/matorrales o árboles pequeños, generalmente para ovejas y cabras, y árboles grandes, para ganado vacuno y búfalos. Se sabe que algunas especies aumentan o disminuyen la producción de leche y grasa láctea. Otras, provocan disfagia, hematuria y problemas urinarios. En general, estas especies son ricas en proteína bruta, con una variación del 7,8 al 18,8%. Su contenido de materia seca fluctúa de 40 a 50%.*

Introduction

In Nepal, fodder from more than 100 different kinds of trees and shrubs has been used as animal feed during the winter. Fodder trees and shrubs contribute 28% of the total supply of 5.85×10^6 t total digestible nutrients (TDN) (Joshi 1988). More than 75% of the tree and shrub fodders are used from November to June (Panday 1981).

In Nepal, fodder plants are privately owned or the fodders are collected from forest trees. The annual yield varies from 20 to 400 kg/tree, depending on species, locality (climate × soil), age, season, and method of lopping. Species of the high hills (e.g., *Quercus semecarpifolia*, *Quercus lamellosa*, *Symplocos crataegoides*) are late contributors, taking 5–10 years to become reasonably useful as fodder trees. The hill species (e.g., *Litsea polyantha*, *Ficus roxburghii*, *Leucaena leucocephala*) take 2–10 years to produce a full dry matter (DM) yield of 15–60 kg/tree per year (Panday 1982). *Ficus glaberrima*, thought to be the most productive fodder tree, can yield as much as 400 kg/year of fresh fodder.

Most fodder trees and shrubs supply firewood and timber (*Shorea robusta*, *Dalbergia sissoo*); fruit (*Artocarpus lakoocha*, *Eugenia jambolana*); vegetables (*Bauhinia variegata*, *Ficus lacor*); green manure (*Villebrunea frutescens*, *Sesbania grandiflora*); and soap and fat (*Bassia butyracea*); and are used for agricultural tools (*Schima wallichii*), basket making (*Bambusa* spp. and *Arundinaria* spp.), and in medicine (*Terminalia chebula*, *Terminalia belerica*).

Fodder trees and shrubs contribute significantly to the Nepalese farm economy. However, little attention has been paid to

- exploring better propagation techniques,
- assessing their nutritive values, and
- integrating different concerned agencies (e.g., forestry, agriculture, animal science, industry, and education) to encourage farmers to increase fodder tree plantations in marginal land.

The chemical compositions of some fodder trees and shrubs have been reported by a few workers in Nepal (Pradhan 1981; Panday 1982; Bajracharya et al. 1985; Jha et al. 1988). Problems such as dysphagia, decreased milk yield, hematuria, and urinary disturbances exist in animals fed with some species of trees and shrubs in many parts of the country.

Geographical distribution

There is no clear-cut demarcation that a particular species of fodder tree or shrub should be available in a particular area. Most of them have a fairly wide adaptability. Trees like *Ficus lacor* and *Artocarpus lakoocha* are found growing in the Terai as well as in the hills (up to 2 000 m) and trees like *Quercus semecarpifolia* and *Quercus lamellosa* are found in the high hills (2 000–3 000 m). There are 31, 98, and 20 species of fodder trees and shrubs in the Terai (m), the hills (800–2 000 m), and the high hills (2 000 m), respectively.

The most important species in the Terai, in order of preference by farmers, are the following: *Artocarpus lakoocha*, *Litsea polyantha*, *Leucaena leucocephala*, *Garuga pinnata*, and *Melia azedarach*. The noncultivated species include *Shorea robusta* and podar (botanical name not known). In the hills, *Artocarpus lakoocha*, *Litsea polyantha*, *Grewia oppositifolia*, *Premna bengalensis*, *Wendlandia exsertia*, *Cleyera ochnacea*, *Ficus clavata*, and *Ficus glaberrima* provide the majority of green fodder. In the high hills, *Quercus semecarpifolia*, *Quercus lamellosa*, *Salix babylonica*, and *Arundinaria intermedia* provide most of the green fodder during the winter.

During the last decade, farmers who migrated to the Terai brought some propagatory materials with them and, thus, numerous fodder trees now grow around their farms. Farmers in the high hills depend on the natural supply of tree fodders. Tree fodders in the Terai and the midhills are obtained from privately owned marginal land, terrace banks, and forests. Forest tree and shrub fodders include *Shorea robusta*, *Dalbergia sissoo*, *Asparagus racemosus*, *Brassaiopsis hainla*, *Castanopsis tribuloides*, *Celtis australis*, *Disporum cantoniense*, *Eurya japonica*, and *Grewia tiliaefolia*.

Patterns of use

Fodder trees and shrubs are lopped and fed fresh to livestock throughout Nepal. Usually, animals in production get first priority for green leaves. The uneaten woody twigs are dried and used for fuelwood. In Jumla (3 000 m) and some other parts of the country, however, twigs from *Salix babylonica* are harvested in the autumn and piled in stacks over the tree arches and fed to the animals in the winter when they cannot be taken out for grazing.

The size of the tree, availability of other feed resources, and the type of animals a farmer is maintaining determine the method of lopping. Smaller trees less than 3 years of age are lightly lopped leaving the apical branch untouched. Larger trees, however, are lopped starting from the basal branches and moving to the top. The trees are completely lopped in 1 day or more depending on the number of animals and the kinds of fodder available in the farm. To avoid climbing and lopping fodder from tall trees, few farmers now chop off the apical branches of the young plants of tall-growing species. As a result, trees get bushy rather than slender and tall. Many

Table 1. Trees and shrubs fed to sheep and goats.

Nepali name	Botanical name
Tite pati	*Artemisia vulgaris*
Bans	*Bamboosa arundinacea*
Tanki	*Bauhinia purpurea*
Koiralo	*B. variegata*
Bhorlo	*B. wahlii*
Bhimsenpati	*Buddleja asiatica*
Dhalay kutus	*Castanopsis indica*
Musure katus	*C. tribuloides*
Khari	*Celtis australis*
Dhurseli	*Colebrookia oppositifolia*
Phurke	*Diplomorpha canescens*
Jhingane (sano)	*Eurya japonica*
Jamun	*Eugenia jambolana*
Guenli	*Elaeagnus latifolia*
Faledo	*Erythrina arboroscens*
Khanyu	*Ficus semicordata*
Khasreto	*F. hispida*
Berulo (gedilo)	*F. clavata*
Dudhilo	*F. nemoralis*
Nimmaro (nebharo)	*F. roxburghii*
Dabdabe	*Garuga pinnata*
Gai tihare	*Inula cappa*
Oo-siris	*Leucaena leucocephala*
Bhusure	*Leucosceptrum canum*
Chiple	*Machilus gamblei*
Sindure	*Mallotus phillipinensis*
Bilaune	*Maesa chisia*
Baldhyangro	*Mucuna nigricans*
Chanp	*Michelia champaca*
Kimbu	*Morus alba*
Bakaino	*Melia azadirachta*
Noon dhike	*Osyris weightiana*
Ginderi	*Premna* spp.
Khasru	*Quercus semecarpifolia*
Arkhaulo	*Q. fenestrata*
Gogan	*Saurauia nepaulensis*
Harro	*Terminalia chebula*
Simali	*Vitex negundo*
Chiple ghans	*Villebrunea frutescens*
Dhanyaro	*Woodfordia fruticosa*
Rato phusre	
Kangiyo	*Wendlandia exserta*
Khirro	*Wrightia antidysentrica*
Bayer	*Zizyphus jujuba*

species of small trees and shrubs are used to feed sheep and goats (Table 1). Tall trees, with a positive effect on milk yield, are fed to cattle and buffaloes (Table 2).

Nutritive value

Many trees and shrubs have been analyzed for chemical composition (Pradhan 1981; Panday 1982; Bajracharya et al. 1985; Jha et al. 1988), DM digestibility

Table 2. Trees and shrubs fed to cattle and buffaloes.

Nepali name	Botanical name
Badahar	*Artocarpus lakoocha*
Kurilo	*Asparagus racemosus*
Seto siris	*Albizia stipulata*
Chiuri	*Bassia butyracea*
Tanki	*Bauhinia purpurea*
Koiralo	*B. variegata*
Bhorlo	*B. vahlii*
Bans	*Bambusa arundinacea*
Chuletro (seto)	*Brassaiopsis hainla*
Gayo	*Bridella retusa*
Githi	*Boehmeria regulosa*
Khari	*Celtis australis*
Baklopate	*Cleyera ochnacea*
Phurke	*Diplomorpha canescens*
Faledo	*Erythrina arborescens*
Timilo	*Ficus auriculata*
Kabro (seto)	*F. lacor*
Pakhuri	*F. glaberrima*
Nimmaro (nebharo)	*F. roxburghii*
Berulo (gedilo)	*F. clavata*
Pipal	*F. religiosa*
Lankuri	*Fraxinus floribunda*
Pharso	*Grewia tiliaefolia*
Bhima' (sal phusre)	*Grewia oppositifolia*
Dabdabe	*Garuga pinnata*
Birale lahoro	*Hedyotis scandens*
Kutmiro	*Litsea polyantha*
Kimbu	*Morus alba*
Baldhyangro	*Mucuna nigricans*
Dhobini	*Mussaenda macrophylla*
Chanp	*Michelia champaca*
Bilaune	*Maesa chisia*
Simal tarul	*Manihot esculenta*
Ginderi	*Premna* spp.
Painyu	*Prunus cerasoides*
Khasru	*Quercus semecarpifolia*
Bhakaimlo	*R. javanica*
Bhalayo	*Rhus succedanea*
Chilaune	*Schima wallichii*
Sal	*Shorea robusta*
Chiniya	*Schefflera impressa*
Bains	*Salix babylonica*
Gogan	*Saurauia nepaulensis*
Sajh	*Terminalia tomentosa*
Barro	*T. belerica*
Harro	*T. chebula*
Chiple ghans	*Villebrunea frutescens*
Amriso	*Thysanolaena maxima*

(DMD), and organic matter digestibility (OMD) (Pradhan 1981). The DM content of most hill fodder leaves averages 40–50% when sampled from October to December (Pradhan 1981). Among the 19 species taken in the study, a maximum DM content of 63% was observed in *Grewia oppositifolia* in December and a minimum of 40% was found in *Saurauia napaulensis* in the same month (Table 3). Pradhan (1981) also reported an average crude protein (CP) content of 12.0% in *Schima wallichii* and 15.7% in *Albizia stipulata*. Panday (1982) reported an average DM content of 36% in 29 species; a maximum of 51% was found in *Albizia stipulata* and a minimum of 37% was observed in *Ficus roxburghii*. Similar variations exist in CP content. Other studies have also found such differences, even within species (Bajracharya et al. 1985; Jha et al. 1988). These differences could be associated with one or more of the following factors:

- season of lopping,
- locality (climate × soil),
- sampling techniques, and
- analytical procedure.

In vitro OMD studies conducted by Pradhan (1981) found that the fodder leaves of *Artocarpus lakoocha*, *Salix babylonica*, *Michelia champaca*, *Ficus semicordata*, and *Brassaiopsis hainla* contained more than 40% OMD. A similar study by Panday (1981) revealed that farmers' preference for tree fodders did not correspond to metabolizable energy contents. Panday (1981) also reported that most of fodder trees have wide calcium/phosphorus ratios and that species like *Brassaiopsis hainla* and *Ficus roxburghii* are fairly rich in potassium.

Farmers' preference for fodder trees or shrubs are partially based on the effect a particular species has on milk or milk fat production. Species with known ill effects are not fed to animals in production. The following species are known to increase milk yield in both cattle and buffaloes: *Artocarpus lakoocha*, *Cleyera ochnacea*, *Ficus clavata*, *F. religiosa*, *Grewia oppositifolia*, *Garuga pinnata*, *Mucuna nigricans*, *Litsea polyantha*, *Populus* spp., *Premna bengalensis*, and *Wendlandia exsertia*. *Bassia butyracea*, *Grewia oppositifolia*, *Litsea polyantha*, and *Premna bengalensis* are known to increase milk fat production.

Fodder yield

Despite the fact that fodder trees and shrubs contribute a significant quantity of winter fodder, little work has been done on evaluating their yields. In general, fodder yield of any tree or shrub is influenced by species, its age, moisture, fertility status of soil, season of lopping, severity of lopping, and severity of weather.

Annual fodder yields vary from 20 to 400 kg fresh/tree (Panday 1982; Pradhan 1982; Shrestha 1988). *Ficus lacor*, for example, yields 150 kg/year, whereas *Ficus glaberrima* yields as much as 400 kg/year of fresh fodder from a well-managed, 10-year-old tree.

Other uses of fodder trees and shrubs

The second-most common use of fodder tree and shrub species is firewood. Fodder trees and shrubs are lopped along with the twigs and offered to animals; the remaining woody branches are dried and used as firewood. Other uses include

Table 3. Chemical composition (% dry matter basis) of the fodder of some trees and shrubs.

Species	% DM	CP	NFE	EE	CF	Total ash	DMD	OMD
Albizia stipulata	51.5	15.7				7.6	27.8	23.3
Artemisia vulgaris		16.4	54.4	4.2	16.1	8.9	68.8	69.6
Artocarpus lakoocha	31	14.8	48.8	2.5	22.8	11.4	56.6	48.9
Arundinaria intermedia	53.5	9.8		1.2	20.7			
Azadirachta indica	36	15.0	57.0	3.0	13.8	10.6		
Bambusa acundinacea	42	22.3	38.6	2.3	23.3	13.3		
Bauhinia purpurea	30	29.7	31.7	3.7	25.2	9.8	49.1	39.8
B. variegata	49	19.6	33.4	4.2	28.3	14.6		
Berberis asiatica	31.2	5.9		1.2		7.1		
Brassaiopsis hainla	21	21.6	45.3	3.0	20.4	9.7	65.5	56.1
Buddleja asiatica	31	19.8	44.2	4.4	21.8	9.9		
Bridella retusa	49.5	11.9				9.8	42.0	33.2
Castanopsis indica	35	14.8	47.9	2.6	29.4	5.3		
C. tribuloides	48.5	8.2		2.8		4.9		
Cedrela toona	44.5	6.2		5.2		11.2		
Celtis australis	64	11.4				28.8	41.5	26.8
Dendrocalamus strictus	48	15.5				14.2	39.1	33.8
Dalbergia sissoo	40	16.6	49.4	3.2	22.2	8.6		
Eurya acuminata	40	8.2		3.7		6.9		
Erythrina arborescens	37.0	16.8		6.1		10.6		
Ficus semicordata	44	14.0	40.2	2.8		31.3	55.6	44.2
F. clavata	32	18.0	40.6	3.3	20.5	17.6		
F. lacor	42.0	13.0	51.8	2.8	21.3	11.2		
F. nemoralis	30	13.4	51.1	4.3	19.0	12.2		
F. roxburghii	37	18.3	39.7	4.5	36.8	11.3		
F. glomerata	44	12.4				22.2	49.4	33.6
F. hispida	31.7	24.2	35.3	4.1	23.9	12.4		
Garuga pinnata		10.0	52.8	5.0	17.8	14.5		
Grewia tiliaefolia	35	19.5	46.6	3.4	18.7	11.9		
G. oppositifolia	63	15.0				8.6	35.6	27.5
Hedyotis scandens	25.8	9.7		3.0		10.3		
Leucaena leucocephala	35.6	26.6	39.6	5.9	14.3	13.7		
Litsea polyantha	40.0	13.2				8.9	38.5	34.7
Lagerstroemia parviflora	43	1.1		2.3		9.3		
Machilus odoratissima	53	13.9				4.5	42.3	39.6
M. gamblei	35	10.9	55.4	2.9	26.9	3.9		
Mallotus philippinensis	52	10.5		3.6		6.9		
Michelia champaca	49	14.1				4.6	64.9	64.2
Morus alba	46.8	10.7		6.8		12.5		
Premna bengalensis	23	21.2	41.2	3.7	23.2	10.7		
P. integrifolia	35.1	19.5	48.4	3.0	17.0	12.0		
Prunus cerasoides	43.5	11.6	58.7	4.0	12.5	13.2		
Quercus lamellosa	54.5	12.2				4.1	15.4	33.2
Q. semecarpifolia	69.2	8.7		7.6		3.1		
Q. lanuginosa	6[illegible]	56		1.4		2.5		
Rhus jayanica	37.3	9.3		6.7		9.1		
Salix babylonica	52.0	18.8				10.3	55.7	51.2
Saurauia napaulensis	40.0	6.2				1.1	55.1	55.8
Schima wallichii	52	12.0	59.6	3.2	2.13	1.1	55.1	58.8
Wendlandia exserta		8.1				5.3		

Note: DM, dry matter; CP, crude protein; NFE, nitrogen-free extract; EE, ether extract; CF, crude fibre; DMD, dry matter digestibility; OMD, organic matter digestibility.

Source: Panday (1982), Pradhan (1982), Bajracharya et al. (1985), Gupta and Balaram (1988), Jha et al. (1988).

timber, fibre, live hedges, basket and mat making, agricultural tools, paints, medicines, etc.

- Firewood: *Shorea robusta*, *Schima wallichii*, and all fodder twigs of other species not eaten by animals.
- Timber: *Shorea robusta*, *Dalbergia sissoo*, *Bambusa* spp., and *Bombax malabaricum*.
- Agricultural tools (ploughs, yokes, spade handles, rakes, etc.): *Schima wallichii*, *Shorea robusta*, *Castanopsis indica*, *Salix babylonica*, and *Quercus lamellosa*.
- Live hedges: *Adhatoda vasica*, *Erythrina arborescens*, *Vitex negundo*, and *Wrightia antidysentrica*.
- Green manure: *Adhatoda vasica*, *Castanopsis indica*, *Artemisia vulgaris*, *Colebrookea oppositifolia*, and *Wrightia antidysentrica*.
- Fruit: *Artocarpus lakoocha*, *Castanopsis indica*, *Castanopsis tribuloides*, *Ficus semicordata*, *Eugenia jambolana*, and *Zizyphus jujuba*.
- Vegetables and pickles: young flowers and buds of *Bauhinia variegata*, *Brassaiopsis hainla*, and *Ficus lacor*, and young culms of *Bambusa* spp.
- Fibre: *Bambusa* spp., *Ficus glaberrima*, *Salix babylonica*, and *Sesbania* spp.
- Baking powder: *Machilus gamblei*.
- Medicine: roots or shoots (bark) of *Bauhinia purpurea*, *Bauhinia variegata*, *Aegle marmelos*, *Garuga pinnata*, *Michelia champaca*, *Terminalia belerica*, and *Terminalia chebula*.
- Gums: fruit sap of *Aegle marmelos* and shoot sap of *Populus* spp.
- Vegetable fats and soaps: fruits of *Bassia butyracea*, and *Azadirachta indica*.
- Fish poison: leaves of *Buddleja asiatica*, and *Wrightia antidysentrica*.
- Temporary plates: leaves of *Ficus roxburghii* and *Shorea robusta*.
- Resins and house paint: *Shorea robusta*.

Toxic effects of tree fodders

Toxic effects of some of the tree and shrub fodders are well recognized in many farming communities (Table 4). However, the scientific reasons behind these effects are either ill-defined or speculative. Toxic effects with economic significance include dysphagia, decreased milk yield, hematuria, and urinary problems. Dysphagia is usually associated with eating young new shoots or leaves of rough, hairy plants.

Table 4. Toxic effects of tree and shrub fodders.

Effect	Species
Decreased milk yield	*Bambusa* spp., *Bauhinia variegata, Boehmeria regulosa, Bredula retusa, Ficus auriculata, F. semicordata, F. hispida, F. glaberrina, F. roxburghii, Grewia tiliaefolia, Prunus cerasoides, Quercus incana, Shorea robusta*
Dysphagia	*Bridella retusa, Buddleja asiatica, Ficus lacor, F. roxburghii*
Haematuria	*Albizia stipulata, Ficus semicordata, F. nemoralis, Osyris wightiana, Thysanolaena maxima*
Abortion	*Bambusa* spp., *Bauhinia vahlii, Ficus semicordata, F. hispida*
Hair loss, skin disease	*Ficus clavata, Mucuna nigricans, Schima wallichii, Shorea robust*

Recommendations and conclusions

To improve the availability and enhance the use of shrubs and tree fodders in Nepal, the following actions are recommended.

- Launch a nationwide fodder tree plantation program.
- Convert at least 10% of the marginal lands into fodder orchards.
- Include fodder trees or shrubs in grazing land.
- Develop fast and sure propagatory techniques for important fodder trees and shrubs.
- Extend the knowledge of agroforestry systems in the farming community.
- Integrate the national programs for pasture, agriculture, forestry, industry, etc.
- Assess feed values of tree fodders and shrubs.
- Identify the deleterious constituents found in some fodder plants and explore means of detoxification.
- Develop systems of fodder leaf conservation.
- Identify the research centres and provide necessary facilities with proper incentives to researchers and extension workers.
- Initiate studies on feeding values and annual yields of shrubs and tree fodders.

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Availability and use of shrubs and tree fodders in Bangladesh

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Abstract — *This paper highlights the importance of shrubs and tree fodders and their availability and patterns of use as animal feeds in Bangladesh. Shrubs and trees are regarded as good fodder sources in the country. Using shrubs, tree leaves, tender shoots, stems, and twigs as feed for ruminants is a village tradition. The characteristics, types, and uses of common shrubs and fodder trees in the homestead, forest, and common lands are discussed. Institutional support to compile a complete inventory of forage shrubs and trees is necessary as is the need for regulated lopping and grazing in the forest, homestead, and common lands. Indiscriminate lopping often results in the death of desirable shrubs and trees. Special attention should also be directed to determine the nutritive value of various feeds and the nature and extent of various toxic elements.*

Résumé — *L'auteur souligne l'importance des arbres et des arbustes fourragers et précise leur disponibilité et leur utilisation comme fourrage au Bangladesh. Dans ce pays, les arbustes et arbres sont considérés comme de bonnes sources de fourrage. Donner à manger aux ruminants des feuilles d'arbustes et d'arbres, des jeunes pousses, des tiges et des brindilles est une tradition dans les villages. L'auteur aborde les caractéristiques, les types et les emplois des arbustes et des arbres fourragers communs de la ferme, de la forêt et des terres communales. Il affirme qu'il faut une aide institutionnelle pour établir un répertoire complet des arbustes et des arbres fourragers et qu'il s'impose aussi d'en assujettir à des règles l'émondage et le pâturage dans les forêts, dans les exploitations agricoles et sur les terres communales. L'émondage sans discernement aboutit souvent à la mort de bons arbustes et arbres. Il faut aussi s'attarder à déterminer la valeur nutritive des divers fourrages et la nature et l'importance des divers éléments toxiques qu'ils contiennent.*

Resumen — *Este estudio destaca la importancia de forrajes de arbustos y árboles y sus disponibilidades y pautas de utilización como alimento de animales en Bangladesh. Los arbustos y árboles son considerados como buena fuente de forrajes en el país. La población a costumbra a utilizar los hojas de árboles, arbustos, vástagos, tallos y ramitas como alimentación de rumiantes. Se tratan las características, tipos y usos de arbustos y árboles forrajeros comunes en la heredad, bosques y tierras comunales.Es tan necesario que se apoye institucionalmente la confección de un inventario completo de árboles y arbustos forrajeros, como también que la poda y pastoreo en los bosques, la heredad y tierras comunales se efectúe en forma reglamentada. La poda indiscriminada da por resultado, frecuentemente, la pérdida de árboles y arbustos útiles. También debe prestarse especial atención a la determinación*

del valor nutritivo de varios forrajes y a la naturaleza y extensión de diversos elementos tóxicos.

Introduction

Livestock has been an essential component of the farming systems of Bangladesh for centuries. About 98% of draught power for preparing land for cereal crops, a substantial amount of power for transporting goods, meat and milk for human consumption, hides and skins, bones and horns as raw material for industry and export, manure for crop fields, and fuel for domestic use are all derived from the country's livestock. Although this sector's share of gross domestic product was only 6.2% in 1981/82, the indirect contribution through draught or fuel was large (BBS 1983). Gross output has been estimated at 25 × 10^9 BDT annually at current prices, growing at about 6%/year over the past few years (World Bank 1983) (in July 1989, 32 Bangladesh taka [BDT] = 1 United States dollar [USD]). Livestock products are the third largest foreign exchange earner in Bangladesh; 1.3 × 10^9 BDT worth of hides and skin were exported in 1979/80.

Cattle are the most important farm animals. There is about 21.2 million head in Bangladesh; cattle account for about 90% of the country's animal units (BBS 1986). About 0.46 million buffaloes are kept on the new diluvial (char) land of southern and northeastern Bangladesh. The total number of goats was estimated at 8.7 million, of which 40% are male and the remaining 60%, female. Most of the goat population is in the rural area (98%); only 2% is in the urban area. Goats are kept mostly by marginal and landless people to convert small amounts of roughage and browse into meat for sale. Most of the 0.5 million sheep are owned in large flocks by families who have or try to establish special land-use rights in the char areas. The contribution of sheep to the income of average rural families is negligible. Therefore, attention must be focused on goats. The poultry population is estimated at 78.4 million. They are widely distributed among rural households and are generally kept as scavenging birds.

Feed resources

Feeds from arable land

The major feed for livestock in Bangladesh is straw. About 2 kg of straw is available per head per day and supplementation is limited to about 1 kg of green fodder plus marginal quantities of cereal and oilseed by-products. Leguminous cash crops and pulses are mostly grown for grain, but their straw is also fed to livestock. Bangladesh produces a variety of different oilseeds. The most important of these are mustard and rape, with a total production of 116 000/year in 1980 (BBS 1983). These nonleguminous crops provide most of the oil cakes used as livestock feed. The balance is produced with sesame and groundnuts, with a combined production of about 50 000 t/year.

Feeds from nonarable land

Nonarable land contributes most of the green fodder for ruminants in the country. With the extreme pressure on land, it must be considered as an important future source of feed. Nonarable land at the farm level is found around pond embankments, on bunds, and around homesteads. Outside the farms, it is usually public wasteland found along canals, rivers, roadsides, and railways. The Bangladesh Department of Forestry has planted arhar (pigeon pea, *Cajanus cajan*) along roadsides in different districts. The legume ipil-ipil (*Leucaena leucocephala*) has also been introduced. Trials have been made to grow traditional grasses like para grass (*Brachiana mutica*), napier grass (*Pennisetum purpureum*), guinea grass (*Panicum maximum*), and pangola grass (*Digitaria decumbens*) in some areas by the Directorate of Livestock Services. Results have been unsatisfactory.

Importance of shrubs and tree fodders

The permanent use of arable land for fodder production is not part of traditional land use. Arable land is used for food and cash crops and there is no scope for fodder production in the near future. Forage species that are late maturing have no place in smallholder agriculture. However, many farmers cultivate leguminous forage species as cash crops at the end of kharif, using residual soil moisture and soil crops that can be planted with little or no tillage. Khesari (*Lathyrus sativa*) and matikalie (*Phasecolum aconitifus*) are the species most commonly used.

Although Bangladesh has no arable land for fodder production, there are numerous unconventional sources of feedstuffs for livestock. Among these, shrubs and tree fodders are important. Using shrubs and tree leaves, tender shoots, and twigs as fodder for ruminants is traditional in the villages of Bangladesh. Cultivation of these shrubs requires no extra arable land or labour. The use of shrubs and tree fodder as livestock feed has recently been increasingly recognized. In fact, more animals are now fed on shrubs and tree fodders than on traditional grasses. The growing importance of shrubs and leaf fodders in the livestock economy of the country has necessitated the planing of trees in bunds, riversides, waysides, and homesteads.

Information on the feeding pattern and use of shrubs and tree fodder for animals in Bangladesh is lacking. About one-third of Bangladesh is inundated during the monsoon season. House-cum-pond is typical in most flooded areas and, obviously, water plants are abundant throughout the year. Water hyacinth (*Eichornia crassipes*), which is plentiful everywhere, is unsuitable for cattle and buffaloes as a single feed; however, it can be fed to cattle and buffaloes mixed with rice straw. Dhaincha (*Sesbania aculeata*), a large shrubby herb 300–400 cm long with small leaves, is a useful fodder for goats and sheep. It is cultivated before the monsoon season.

Banana leaves and stems are another promising source of green roughage. Large quantities can be produced under rain-fed conditions on nonarable land. Banana is a cash crop producing the fruit for human consumption and the leaves and stems as fodder for ruminants. When fed to animals, the leaves and stems are chopped and mixed with straw. This mixture is an important green roughage for ruminants during floods and drought.

Table 1. Chemical composition (g/100 g dry matter) of traditional grass species, common shrubs, and tree fodders for livestock in Bangladesh.

Species	Dry matter (%)	Crude protein	Crude fibre	Ether extract	N-free extract	Total ash	Source
			Traditional grasses				
Para grass (fresh)	24.3	3.2	25.9	1.1	59.8	10.1	Saadullah (1988)
German grass (fresh)	18.6	9.8	35.6	2.2	36.9	11.0	Saadullah (1988)
Pangola grass (fresh)	36.3	9.8	36.2	2.6	45.9	5.8	Saadullah (1988)
			Shrubs and tree fodders				
Benian leaves	34.2 (88.9)[a]	12.2	23.1	2.1	41.6	5.1	Ali (1981)
Ipil-ipil leaves	88.5	25.0	16.0	4.6	46.8	7.2	Saadullah (1981)
Banana leaf meal[b]	90.8	15.5	25.5	9.5	30.0	19.8	
Water hyacinth leaves (sun dried)	92.0	26.0	13.2	2.5	51.6	6.8	Saadullah (1981)
Pakar leaves (sun dried)	87.4	14.3	29.1	3.3	36.2	4.9	Ali (1981)
Karie leaves (sun dried)	95.6	16.6	26.6	2.7	42.3	6.3	Ali (1981)
Sisoo leaves (fresh)	37.1	20.2	21.8	4.9	45.0	8.0	Khan (1965)
Mango leaves (fresh)	44.0	8.1	28.1	2.7	50.6	10.0	Khan (1965)
Jam leaves (fresh)	38.9	7.9	20.7	2.6	61.7	7.0	Khan (1965)

[a] Dry matter content of sun-dried leaves.

[b] Source: D. Hossain and S.M. Bul Bul (personal communication).

Table 2. Live weight at slaughter and other physical characteristics of Black Bengal goats fed different ratios of dhaincha (*Sesbania aculeata*) and roadside grasses.

Characteristic	Dhaincha:grass		
	100:0	50:50	0:100
Live weight at slaughter (kg)	16	13	11
Dressing %	62	57	45
Body length (cm)	58	56	55
Leg length (cm)	47	47	43
Width through shoulders (cm)	12	10	9
Width through hips (cm)	14	13	13
Width through legs (cm)	18	16	15
Body depth (cm)	25	25	24
Leg circumference (cm)	23	23	22

Source: Alam et al. (1978).

Leaves from various trees like jackfruit (*Artocarpus heterophyllus*), babla (*Acacia arabica*), mander (*Erythrina oralifolia*), karaie (*Albizia licida*), shewara (*Streblus asper*), and bamboo (*Bambusa tulda*) are fed to goats and sheep all over Bangladesh. Forest areas are almost all reserved and beyond the reach of most livestock. In spite of this, forests are important local sources of fodder and grazing, resulting in perpetual problems in forest management. Cattle and buffaloes graze in the forest when there is no other grazing land or when the forests provide better grazing than available grazing land. Goats are often excluded from reserved forests, but are permitted to browse in controlled forests. Lopping is common in most forests.

Information on the potential value of various shrubs and tree fodders as feeds for livestock in Bangladesh is lacking. Sporadic research has been conducted at the Bangladesh Agricultural University and the Animal Husbandry Institute in Dhaka. There is a variety of forage supplements throughout the country. They are traditionally used by farmers in the feeding systems of ruminants because of their easy accessibility, their wide variety, and because they reduce the requirement for expensive concentrates. Comparing the feeding values of grasses with those of shrubs and leaf fodders, relative nutritive values of the latter are not lower than the traditional grasses (Table 1). In fact, with trees and shrubs, nutritive values fluctuate less.

Dhaincha is a very palatable feed for goats. Studies have been done to determine its palatability and digestibility with Black Bengal goats (Alam et al. 1978; Alam and Wahed 1980). The dry matter intake and digestibility were 1.6 kg/100 g live weight and 66%, respectively. Black Bengal goats fed only dhaincha also showed a higher dressing percentage (Table 2).

Some research on the value of water plants as a supplement has also recently been performed (Khan et al. 1981; Hamid et al. 1983; Haque and Saadullah 1983; Saadullah 1984). It appears that supplementation of about 6 kg water hyacinth (7% dry matter) with rice straw could improve daily feed intake, live weight gain, and dressed carcass weight (Table 3). It also appears that water hyacinth as green supplement results in a better growth rate than traditional napier grass (Table 4).

Shrubs and tree leaves are believed to be important sources of protein for ruminants. In view of this, Huar and Saadullah (1988) studied the ruminal

Table 3. Various characteristics of calves fed rice straw (RS) with and without water hyacinth (WH) (*Eichornia crassipes*).

Characteristic[a]	Untreated RS		Urea-treated RS	
	+ WH[b]	− WH[c]	+ WH[b]	− WH[c]
Straw DMI (kg/day)	2.6	5.4	2.6	5.2
Fresh WH intake (kg/day)	6.5	—	6.3	—
LW gain (g/day)	114	132	227	227
Dressing %	35	32	36	36
Rumen/reticulum contents (% LW)	22	26	21	22

Source: Haque and Saadullah (1983).
[a] DMI, dry matter intake; LW, live weight.
[b] 250 g oil cake/day per calf.
[c] 500 g oil cake/day per calf.

Table 4. Characteristics of calves fed rice straw (RS) with water hyacinth (WH) (*Eichornia crassipes*) or napier grass (NG) (*Pennisetum purpureum*).

Characteristic[a]	Urea-treated RS		Untreated RS
	NG	WH	NG
DMI (kg/day)	2.5	2.5	2.3
Feed conversion (kg DM/kg LWG)	11.0	8.5	21.0
LWG (kg/day)	226	295	107

Source: Hamid et al. (1983).
[a] DMI, dry matter intake; DM, dry matter; LWG, live weight gain.

Table 5. Nylon bag degradability (%) of crude protein of leaves commonly used as livestock feed in Bangladesh.

Species	Incubation time (h)						
	3	6	9	12	24	48	72
Jackfruit	34	37	44	81	83	89	90
Ipil-ipil	40	44	58	68	80	85	86
Napier grass	33	35	37	58	69	77	78
Mango	31	33	37	46	63	68	71
Mander	33	43	44	55	57	60	61
Banana	47	49	53	54	55	57	60
Bamboo	35	37	39	39	41	45	51

Source: Huar and Saadullah (1988).

degradability of dry matter of various tree leaves traditionally fed to the ruminants in Bangladesh. The low degradability of bamboo leaves, followed by banana and mander leaves, indicates the possible availability of higher amounts of undegraded protein in the abomasum (Table 5). Saadullah et al. (1983) reported that the degradability of oil cakes was found to be extensive compared with fish meal, dhaincha, matikalie, and ipil-ipil (*Leucaena leucocephala*) (Fig. 1).

Ownership and growing patterns

Trees, bushes, vegetables, and spices are grown mostly on homestead area. The species available in the homestead have some ecospecificity that determines their

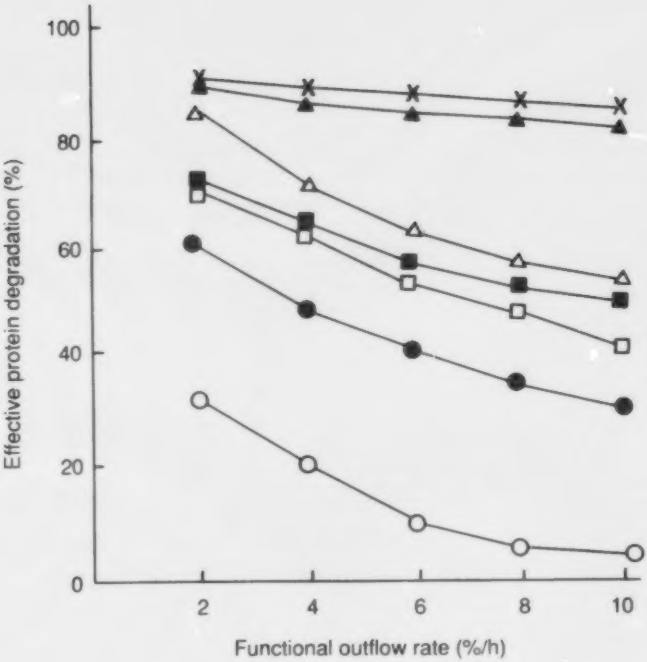

Fig. 1. Effective protein degradation in the rumen as a function of outflow rate: ×, mustard oil cake; ▲, sesame oil cake; △, soybean meal; ■, dhaincha; □, matikalie; ●, ipil-ipil; ○, fish meal (source: Saadullah et al. 1983).

coexistence with livestock, poultry, humans, and the environment. Such plants have diverse uses. The growing pattern is generally spontaneous, that is, without purpose or care for propagation.

Khan et al. (1988) reported the existing agroforestry practices, ownership of trees in relation to landholding, and growing pattern in the homestead of different villages at the Farming Systems Research Site in the Jamalpur district of Bangladesh (Table 6). The results indicated that, for landless farmers, 47% of the total available land was occupied by the homestead; for large farmers, this was only 7%. The ownership pattern of the homestead greatly influenced the plantation. The tendency to plant was better (70%) with single-owner farms than with large farms. On the basis of availability and intensity of the plant species in the homestead, trees with diverse uses (fuel, animal feed, fuel, and fruit) are dominant. The number of trees per household or family was 7.5, 4.0, 12.4, 1.6, 1.7 and 1.0 for jackfruit, mango (*Mangifera indica*), banana, bamboo, jekka (*Lannea grandis*), and mander, respectively (see Table 1). It is important to note that the leaves or stems from these trees are useful fodders for cattle, goats, and buffaloes. Khan et al. (1988) reported also that the growing pattern of 56% of the trees was spontaneous; the rest of the trees (44%) were planted purposely. For plants species, the initial establishment needs care, but, once established, lateral propagation is spontaneous, for example, banana and bamboo.

Table 6. Shrub and tree fodder species available in the homestead in relation to land area.

Common name	Botanical name	Plants per family[a]				Total (all families)	Growing pattern	
		Landless	Marginal	Small	Large		Wild	Cultivated
Aswath tree	*Ficus religiosa*	0.0	0.0	0.1	0.1	0.1	100	0
Babla	*Acacia arabica*	0.3	0.2	0.4	0.3	0.3	100	0
Bamboo	*Bambusa tulda*	1.5	2.0	3.5	3.0	1.9	—[b]	—[b]
Banana	*Musa sapientum*	20.0	27.0	74.0	47.0	29.5	—[b]	—[b]
Banyan tree	*Ficus bengalensis*	0.0	0.0	0.1	0.1	0.1	100	0
Black berry	*Engenia jambolanum*	0.2	0.5	1.0	1.5	0.5	60	40
Cane	*Chrysalidocarpus roxburghii*	0.2	0.3	1.0	0.5	0.4	100	0
Coral tree	*Erythrina indica*	0.4	0.6	2.2	1.0	0.7	0	100
Demur	*Ficus glomerata*	0.0	0.2	0.3	0.2	0.1	100	0
Ipil-ipil	*Leucaena leucocephala*	0.2	0.1	0.9	1.0	0.3	0	100
Jackfruit	*Artocarpus heterophyllus*	6.2	6.4	16.6	8.8	7.5	10	50
Jekka	*Lannea grandis*	1.0	1.2	4.5	4.5	1.7	0	100
Jujuba	*Zizyphus jujuba*	0.4	0.8	3.3	2.2	1.0	60	40
Mandar	*Erythrina oralifolia*	0.6	0.8	1.4	3.4	1.0	0	100
Mango	*Mangifera indica*	3.0	4.6	9.2	5.4	4.0	50	50
Neem	*Azadirachta indica*	0.2	0.4	0.9	0.3	0.3	80	20
Rain tree	*Enterolobium saman*	0.3	0.1	1.0	0.0	0.3	90	10
Shilkari	*Albizia licida*	0.2	0.4	1.2	0.6	0.4	40	60
Shoera	*Streblus asper*	0.5	0.3	0.8	0.6	0.5	100	0
Simul	*Bombax malabaricum*	0.2	0.2	0.4	0.2	0.2	80	20
Sisoo	*Dalbergia sisoo*	0.1	0.1	0.7	0.6	0.2	0	100
Tamarind	*Tamarindus indica*	0.4	0.2	0.9	0.9	0.4	85	15

Source: Modified from Khan et al. (1988).

[a] Landless, 0.01–0.49 acres; marginal, 0.50–0.99 acres; small, 1.00–7.49 acres; large, >7.50 acres (1 acre = 0.405 ha).

[b] Initially cultivated, then grown wild.

Potential sources of shrubs and tree fodders

There is considerable potential for increasing fodder production. On arable land, this could be done using straw or additional cash crops intercropped with food or other cash crops. On nonarable land, permanent vegetation must be emphasized, yielding large amounts of biomass and maintaining the available shrubs and tree fodders for lopping and browsing by livestock. The description of shrubs and fodder trees presented here is based on Khan (1965). These shrubs and trees provide not only fodder for livestock but also fuel, fruits, and timber. Most are flood tolerant and provide fodder during dry periods, when leaves and twigs are the only alternative feeds. Trees are lopped whenever and wherever they are found. Although the demand for shrubs and tree fodders is likely to decrease by improving pasture management and fodder storage, trees and shrubs should be included as a stable constituent of rangeland. Lopping may be regulated where it is unavoidable, but it is essential that fodder trees be grown along with other species in plantations to create fodder reserves against periods of scarcity.

Shrubs

Several fodder shrubs are found in Bangladesh:

- Asaria (*Capparis horrida*): A climbing shrub with shoots and leaves covered with pubescence; leaves, oblong, elliptic, 5–10 cm long; found throughout; leaves and twigs eaten by goats and cattle.
- Aswagandha (*Withania somnifera*): An evergreen undershrub 2–12 cm high; leaves thin, ovate; found throughout; fodder for goats.
- Bamboo (*Bambusa* spp.): Bamboos are eagerly browsed by cattle and goats.
- Begoon (*Solanum indicum*): An erect, 30–150 cm high shrub; prickles on the petioles and leaves; leaves ovate and truncate, base cordate or unequal sided; found throughout; leaves are fodder for goats.
- Bhai-birrung (*Embelia robusta*): A large, rambling shrub with sprawling branches; leaves, 6–15 cm by 4–8 cm, entire, elliptic, or ovate, thick pale beneath; found in Mymensingh district and Chittagong; medium quality fodder.
- Chhagul buti (*Daemia extensa*): An extensive, slender, twinning shrub; leaves, opposite, 2–7 cm long, broadly ovate or suborbicular, base deeply cordate; found throughout; fodder for goats.
- Delup (*Saurauja roxburghii*): A small evergreen, branches with white lenticels; leaves, 20–40 cm long with strong parallel veins diverging from the midrib; found in Chittagong forests and sometimes cultivated in villages for fodder; good fodder for goats.
- Dhaincha (*Sesbania aculeata*): A large, shrubby herb 300–400 cm long with small weak prickles on branches and leaf rachis; leaves, 2–3 cm long, leaflets 20–40 pairs linear; cultivated throughout Bangladesh as green manure and sticks for fuel; leaves are useful fodder and liked by goats and cattle.
- Guya-babul (*Acacia farnesiana*): An erect, thorny shrub, evergreen with light

brown rough bark; cultivated in different areas; leaves and green pods are excellent feed for sheep and goats.

- Juva (*Hibiscus rosasinensis*): A native of China, it was introduced as an ornamental; a large, evergreen shrub; leaves, 7–10 cm long, ovate, coarsely toothed; cultivated in gardens as hedge or ornamental; browsed by goats and cattle.
- Kabra (*Capparis decidha*): A prostrate and trailing species; leaves, broad orbicular; found throughout; medium quality fodder for goats.
- Kak dumur (*Ficus hispida*): A shrub or small tree; throws up abundant root suckers, branches stout, often hollow, marked by the scars of petioles and stipules; found throughout; a good fodder species.
- Kala, banana (*Musa sapientum*): A shrub-like herb, 150–350 cm high; thick stems, composed of convolute leaf sheaths; leaves very large, many-flowered petals shorter than calyx; wild and cultivated throughout Bangladesh; cattle feed during drought and flood.
- Lal-jhau (*Tamarix dioica*): A gregarious shrub, bark reticulately cracked, grows along open stream; twigs not articulate; leaves sheathing with a broad white margin; found in the hilly region; medium quality fodder.
- Madhubilata (*Hiptage madablota*): A large, evergreen, woody, climbing shrub; branchlets, young leaves, and inflorescence hoary or with a depressed tomentum, mature one is glabrous; found in Chittagong forest area, also cultivated in other parts of Bangladesh; medium quality fodder.
- Mankanta (*Randia dumetorum*): A large, deciduous, thorny shrub or a small tree; leaves, 3–7 cm by 1–5 cm, stipulate ovate acuminate; found in Sal forest, Mymensingh district; medium value for goats.
- Mathara (*Callicarpa macrophylla*): An erect, evergreen, 200–250 cm high shrub; twigs, petiole, peduncle, and leaves beneath densely wooly tomentose; found throughout; good fodder species.
- Nishinda (*Vitex negundo*): A large shrub; bark thin grey, branches whitish with fine tomentum; leaves opposite, digitately 3–5 foliate; found in Sunderbans and Chittagong; medium quality fodder in times of scarcity.
- Pola (*Kydia calycina*): A deciduous, soft-wooded, large shrub; young shoots, inflorescence and lower side of the leaves grey or tawny tomentose; leaves palmately 5–7 nerved, having a large gland on 1–3 of the nerves beneath; found throughout; medium to poor fodder, flowers commonly eaten by buffaloes.
- Shoera (*Streblus asper*): A rigid shrub; bark light grey or greenish with faint ridges, rough when old; juicy, milky; twigs, hairy and scabrid; good fodder, fed to cattle, goat, and buffaloes.
- Sun hemp (*Crotalaria juncea*): A large shrubby herb about 250–350 cm long with small weak prickles on branches and leaf; leaves, 4–6 cm long; cultivated in Tangail, Chittagong, Chittagong Hill Tracts, and Comilla district; leaves are valuable feeds for goat, cattle, and buffaloes.
- Tita-konga (*Dregea volubilis*): A stout, large, twinning shrub; branches rough

with raised lenticels; leaves, opposite, 6–15 cm by 4–10 cm; found in hilly areas; browsed by goats and sheep.

- Water hyacinth (*Eichornia crassipes*): An aquatic plant found throughout Bangladesh; grows rapidly and tends to clog streams and ponds in the areas where there is much surface water; valuable feed during drought and flood; fed to cattle and buffaloes.

Fodder trees

The following trees of Bangladesh are useful for fodders:

- Am, mango (*Mangifera indica*): A cultivated, large to medium-sized tree; leaves are dark green, coriaceous; fruit, fleshy drupe; leaves are medium quality fodder for goats and cattle.
- Babla (*Acacia arabica*): An erect, medium-sized evergreen with rough, dark brown bark; wild and planted on riversides or highways; a very good fodder for goats and sheep; pods are fed to cattle.
- Badam (*Sterculia alata*): A tall, large tree with smooth leaves, entire, simple, glabrous; leaves used as cattle feed.
- Bel (*Aegle marmelos*): A small to medium-size tree, young shoots, hairy armed with sharp spines; leaves, alternate, trifoliate; a good fodder species in some areas.
- Bot, banyan (*Ficus bengalensis*): A large tree with rooting branches; branches spreading, sending down numerous aerial roots, which become trunks; wild and planted; lopped for fodder.
- Demur (*Ficus glomerata*): A large or medium-sized tree with figs on leafless branches; mature leaves glabrous; found in the plains; good fodder.
- Jum (*Garuga pinnata*): A large deciduous tree; found throughout; good fodder.
- Kanthal, jackfruit (*Artocarpus heterophyllus*): A large evergreen, 100–150 cm high; leaves, 10–20 cm long, entire, dark green; wild and cultivated throughout Bangladesh, especially in Mymensingh and Dinajpur districts; leaves eaten by goat and cattle; good fodder.
- Kaori (*Albizia procera*): A large, fast-growing timber tree; found throughout; lopped for fodder.
- Kool, barie (*Zizyphus mauritiana*): A large shrub or medium-size tree; branches often drooping, armed with stipular spines; leaves, velvety, tomentose beneath; lopped for fodder for goats and cattle.
- Moala (*Sterculia colorata*): Medium-size tree; branches have large leaf scars; leaves crowded at the ends of branches, broader than long, 3–5 cm lobed; found in the Chittagong and Chittagong districts; twigs and leaves are used as cattle fodder; good fodder species.
- Neem (*Azadirachta indica*): A large evergreen tree; found throughout; leaves are eaten by goats and sheep; good fodder.

- Rain tree (*Enterolobium saman*): A large evergreen that grows exceedingly fast; wild and cultivated; a fairly good fodder for cattle.
- Safed-babul (*Acacia leucophloea*): A medium-size deciduous tree; fed to goats and sheep; pods are fed to cattle in some regions.
- Sajna (*Moringa pterygosperma*): A medium-size to large tree that can be propagated by cuttings; young parts tomentose; leaves usually tripinnate; young pods are used for pickling and cereal; a good fodder species; branches are lopped for fodder; goats are especially fond of sajna.
- Sal (*Shorea robusta*): A large gregarious, deciduous tree, but seldom leafless; leaves glabrous and shining when mature, 10–25 cm long, base rounded or cordate; found in the forest area of Mymensingh, Chittagong, Khulna, and Dhaka districts; medium quality fodder at times of scarcity.
- Sisoo (*Dalbergia sisoo*): A medium-size to large tree; leaves are imparipinnate; wild and has been planted in the north east; frequently lopped for fodder.
- Tetul, tamarind (*Tamarindus indica*): A very large, unarmed evergreen with dark grey bark; leaves, even, pinnate, opposite, 10–20 pairs, 1–2 cm long; found throughout; good fodder.
- Tiktashk (*Crataeva religiosa*): Medium-size deciduous tree with large white lentils on the branches; leaves clustered at the ends of branchlets, trifoliate; found throughout; cultivated for its handsome flowers and fruits; leaves are lopped for fodder.
- Tut (*Morus indica*): A deciduous tree; leaves truncate or rounded, the base of some is slightly cordate and narrows into an acuminate apex; cultivated and wild in Rajshahi and Dinajpur districts; good fodder.

Availability of by-products

Using information on land area and total yield of fruit trees (BBS 1983), the availabilities of individual tree and crop by-products have been calculated (Table 7). In some parts of Bangladesh, by-products are fed to livestock when feed is scarce. The extraction rates suggested by Devendra (1988) and Tareque and Saadullah (1988) have been used. Recycling of these wastes as animal wastes would be possible only after valid assessments of benefits, costs, risks, and toxicity have shown that benefits substantially outweigh costs and risks.

Toxicity

In Bangladesh, little is known about the toxicity of various shrubs, tree fodder, and wastes. The presence of tannins, HCN, or prussic acid may kill an animal. Devendra (1988) summarized the various toxic principles found in common nonconventional feeds in Asia. Sobhan et al. (1970) reported that young shoots of bamboo (*Bambusa bambos*) contain a cyanogenic glycoside (0.0346 mg/100 g) and are poisonous. They also found that some plants in the Mymensingh district contained nitrate. Intoxication and death of animals after ingesting green fodder

Table 7. Availability and yield of by-products from fruit trees and field crops in Bangladesh.

Crop	Area (ha × 10^3)	Production (t × 10^3)	Extraction rate (%)	Yield (t × 10^3)
Banana	42	673		
Fruits (skin)			15	101
Stems			80	539
Leaves			30	202
Mango	45	181		
Kernel skin			50	90
Pineapple	15	153		
Waste			25	38
Jackfruit	21	204		
Seeds and skin			50	102
Sweet potato	66	580		
Vines and leaves			30	204
Sugarcane	0.2	7 023		
Bagasse			14	933
Green tops			12	843
Molasses			4	281

Source: BBS (1983).

containing nitrate has been observed in many studies (e.g., Sen and Rahman 1984; Sobhan 1984).

Government policy

A more global view of livestock-sector constraints, development objectives, and support requirements was established in the development plan of 1981–1985. Feed shortages and deficiencies in the health and care of farm animals were identified as major constraints. There is currently no program to improve the fodder production of nonarable land (roadsides, embankments, field bunds, homestead plots) (World Bank 1983). Most nonarable lands are covered with natural grasses and shrubs. The Bangladesh Forestry Department, responsible for most public nonarable land, has begun roadside planting of pigeon pea in some districts. This generates some ruminant feed. The Department also plans roadside planting of fast-growing fuel and timber trees, which might help to increase the availability of tree fodder for livestock feeding. The Directorate of Livestock Services has been promoting the planting of tropical, traditional grasses on nonarable lands; however, lack of management, conservation, and overgrazing have rendered this effort largely unproductive. Of greater significance, the Directorate is planting different fodder trees like ipil-ipil on roadsides and embankments.

Development and future strategies

The high demand for food has forced Bangladesh farmers to use their available land at high cropping intensities. Of a total area of 14.2 × 10^6 ha, some 9.3 × 10^6 ha are cultivable land (World Bank 1983). The unavailability of cultivable wasteland leaves little scope for expanding the current cropped area for traditional fodder production for livestock in the country. Consequently, emphasis must be placed on the development, conservation, control, and use of shrub and tree fodder resources for increased livestock production.

The use of trees as an integral part of pasture requires that factors such as suitability of species, use (fuel, timber, fruit, or fodder), and soil type be determined. The comparative value (fuel, timber, fruit, and fodder) of forage shrubs and trees has to be considered while cultivating these shrubs and trees on homestead or common lands (roadsides, riversides, or embankments). In the hilly region and rain-fed areas of Bangladesh, where fodder cultivation is insufficient, the fodder requirements from shrubs and trees assume greater importance.

People resort to lopping trees and shrubs in the common lands, homestead, and forests. This is due to the large livestock population, the absence of a proper management system, and faulty methods of collecting fodder for animal feeding. Together, these factors may result in the disappearance of fodder trees and shrubs from such areas. Indiscriminate lopping and browsing often result in death of desirable trees and shrubs. Mostly, the trees in private and common lands are ruthlessly lopped. The *Upazilla Parishad* (local government) could minimize this vandalism by encouraging people to plant trees and shrubs on their own land and to cooperate in the use of common lands. Grazing or lopping may be reduced in the early spring to enable the shrubs and trees to become established. This would make it possible to implement rotational grazing.

In reserved forests, lopping and grazing is often forbidden. However, grazing and lopping may also be regulated: some trees may be protected, others may be lopped either on a rotation or special basis. Although foresters have long believed that the intensity of grazing should depend on the carrying capacity of forests, there is little information, based on properly controlled experiments, that could be used to determine optimal grazing incidence. Of course, a moderate amount of grazing in certain circumstances does not harm forests and may aid fire prevention. However, heavily grazed areas frequently become scrub or thorn forest, and are highly susceptible to damage. Therefore, grazing or lopping should be properly regulated if it is to improve the quality and quantity of resources. This may be done by monthly grazing in a particular area or block. Grazing could be limited by executive order or by imposing a nominal fee.

There is an urgent need for a complete inventory of forage shrubs and trees grown in the homestead, common lands, and forests. Such an inventory should cover nutritive value, characteristics, mode of collection, and use. Standard methods of analysis and experimentation are also needed so that the results achieved in different laboratory and countries can be reliably compared. Special attention should also be directed to the nature and extent of toxic substances such as HCN and tannins in shrubs and tree fodders. Studies on effective, low-cost methods of eliminating these toxic elements and their effects are also needed. Institutional support is essential for the intensive production and use of shrubs and tree fodder by small farms in Bangladesh.

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Availability and use of shrubs and tree fodders in Sri Lanka

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Abstract *— In Sri Lanka, shrubs and tree fodders are mainly fed to goats. They are used in large ruminant production only if grain and crop residues are in short supply. Except in the very hilly regions, the most common cultivated tree fodders are* Gliricidia sepium *and* Artocarpus heterophyllus. Leucaena leucocephala *and both thorny and thornless* Erythrina variegata *are important fodders for ruminants. This paper discusses the cultivation and use of shrubs and tree fodders in Sri Lanka, and how they differ from region to region. The limited information available suggests that Sri Lanka has great potential to improve its small ruminant industry by effectively using shrubs and tree fodders.*

Résumé *— À Sri Lanka, les arbustes et arbres fourragers sont donnés à manger principalement aux chèvres. Ils ne servent dans la production de gros ruminants que si les céréales et les déchets agricoles viennent à manquer. Sauf dans les régions très accidentées, les arbres fourragers les plus communément cultivés sont* Gliricidia sepium *et* Artocarpus heterophyllus. Leucaena leucocephala *et* Erythrina variegata *(la variété épineuse et celle non épineuse) sont d'importants fourrages pour les ruminants. L'auteur discute de la culture et de l'utilisation des arbustes et des arbres fourragers à Sri Lanka et montre comment elles diffèrent d'une région à l'autre. Le peu d'information en main sur le sujet laisse croire que ce pays pourrait améliorer substantiellement son industrie des petits ruminants en faisant un usage efficace des arbustes et arbres fourragers.*

Resumen *— En Sri Lanka, el forraje de árboles y arbustos constituye la principal alimentación de las cabras. Se utiliza como forraje de producción para grandes rumiantes solamente si hay escasez de residuos de granos y cultivos. Excepto en las regiones muy montañosas o escarpadas, los árboles forrajeros ms comunes que se cultivan son* Gliricidia sepium *y* Artocarpus heterophyllus. *Un forraje importante para rumiantes es la* Leucaena leucocephala *y la* Erythrina variegata, *con y sin espinas. Este estudio trata el cultivo y uso de forrajes de arbustos y árboles en Sri Lanka, y la forma en que difieren de una a otra región. La limitada información disponible revela que Sri Lanka tiene grandes posibilidades de mejorar su producción de rumiantes pequeños si utiliza eficazmente arbustos y árboles forrajeros.*

Introduction

Shrubs and tree fodders have been used in Sri Lanka as livestock feed since ancient times. Such fodders are the main sources of feed for goats. However, they are less important for cattle and buffaloes. Roughages other than grasses are

Table 1. Livestock population (× 10^3) in Sri Lanka from 1950 to 1986.

Year	Cattle	Buffalo	Goat	Sheep
1950	1 105	522	370	44
1955	1 432	795	491	89
1960	1 562	812	491	52
1965	1 904	1 051	600	35
1970	1 596	736	558	27
1975	1 712	818	547	28
1980	1 644	843	493	28
1985	1 782	967	539	27
1986	1 783	964	534	29

Source: MRID (1985).

Table 2. Livestock population (× 10^3) by agroecological zone, 1986.

Zone	Districts	Cattle	Buffalo	Goat	Sheep
Wet	Colombo, Gampaha, Kalutara, Nuwara Eliya, Galle, Kegalle	287.0	153.9	95.4	0.3
Intermediate					
Wet	Matale, Matara, Badulla, Ratnapura	196.5	110.4	41.3	0.9
Dry	Hambantota, Kurunegala, Puttalam, Moneragala	455.3	333.3	104.2	6.9
Dry	Jaffna, Kilinocchi, Mannar, Vavuniya, Mullativu, Batticaloa, Amparai, Trincomalee, Anuradhapura, Polonnaruwa, Maheweli	843.7	366.6	533.6	29.1

Source: MRID (1985).

important in feeding large ruminants during dry periods, when the yields and quality of grasses deteriorate. The population of sheep in Sri Lanka is small compared with other ruminants (Table 1). They graze mainly on grasses under coconut in the intermediate zone and in uncultivated lands in the dry zone. Goats are the major species of livestock that depend on shrubs and tree fodders. Goat production is mainly confined to the dry zone of the country (Table 2).

Chemical composition of tree fodders and shrubs

Gliricidia sepium and *Artocarpus heterophyllus* are the most popular fodders fed to ruminants in all the agroclimatic zones of the country, up to an elevation of about 1 000 m above sea level. *Erythrina variegata* (thorny) is fed in the low country, dry and wet zones. *Leucaena leucocephala* is fed mainly in the dry and intermediate zones, where the soil is less acidic, favouring the production of this fodder. *Erythrina variegata* grows in the wet regions of the country and is used widely at elevations above 1 000 m above mean sea level. Above this elevation, climatic conditions do not favour the production of other common tree fodders. Generally, these tree fodders are nutritionally superior to the tree fodders that are fed if available (Table 3).

Table 3. Chemical composition (%) of cultivated tree fodders.

Species	DM	Ash	CF	CP	NDF	ADF	H-cell.	Cell.	Lignin	Silica	DMD
Commonly fed											
Gliricidia sepium	19.9	10.0	5.3	27.6	36.1	27.8	8.4	23.9	2.1	1.1	61.5
Artocarpus heterophyllus	29.3	12.0	3.4	14.2	46.9	46.9	0.1	40.3	1.4	2.6	50.8
Erythrina variegata											
Thornless	18.6	10.5	4.8	25.7	50.6	39.1	11.4	35.5	0.9	0.4	52.5
Thorny	32.7	9.1	5.7	26.4	45.7	34.3	11.4	32.6	0.9	1.0	64.5
Leucaena leucocephala	27.6	8.8	5.9	25.8	34.4	28.9	5.5	26.7	1.8	0.2	56.5
Feed if available											
Mangifera indica	43.3	17.2	4.2	13.0	42.4	37.4	5.0	30.3	10.7	0.4	40.2
Agadirachta indica	32.0	13.8	4.8	15.1	34.9	29.4	5.5	23.6	6.0	0.5	57.5
Morinda citifloria	20.0	13.1	6.7	14.0	43.0	38.8	4.2	24.2	13.5	0.5	57.8
Moringa oleifere	23.8	11.6	7.1	23.0	25.4	16.1	9.3	12.1	4.5	0.1	67.0
Musa acuminatacolla	19.8	10.3	9.0	13.2	60.3	47.5	12.9	35.0	3.7	0.2	52.4
Persea gralissima	36.3	9.1	6.9	13.9	41.4	38.8	2.7	26.0	10.6	0.1	56.3
Acacia fernesiana	38.5	8.7	7.0	15.6	24.9	17.7	7.2	12.1	5.4	0.5	69.5
Naturally available											
Adenanthera pavinona	36.1	6.9	3.2	22.2	46.4	28.0	18.4	18.7	8.8	0.6	64.8
Bauhinia recemosa	40.1	11.7	2.7	14.6	44.6	43.7	0.9	42.2	0.5	0.4	24.3
Bambusa vulgaris	41.7	15.0	3.1	17.8	73.8	64.9	8.9	50.9	0.8	5.5	21.2
Ceiba pentiandra	28.2	12.5	4.5	12.1	41.4	29.2	12.2	20.3	6.0	0.3	68.9
Cordia monoica	33.7	13.6	3.7	13.4	69.9	64.3	5.5	54.2	1.1	2.8	23.0
Drypetes sepiaria	51.5	10.5	2.6	8.8	50.7	47.6	3.1	40.3	1.9	3.1	31.5
Ficus religiosa	23.1	11.8	5.3	22.1	40.6	38.9	1.8	36.9	0.9	0.8	57.5
Grewia microcos	40.8	10.5	4.7	15.3	38.0	33.4	4.5	32.8	1.0	0.1	22.4
Grewia tilifoia	42.8	8.0	3.8	13.6	39.8	39.0	0.6	37.8	1.1	0.1	56.5
Manilkara hexandra	55.3	10.2	9.5	9.9	41.2	35.7	5.6	30.0	3.4	0.1	37.0
Strebulus asper	45.0	23.5	6.2	14.6	48.1	47.1	1.0	24.0	7.8	0.1	54.7

(continued)

Table 3. Concluded.

Species	DM	Ash	CF	CP	NDF	ADF	H-cell.	Cell.	Lignin	Silica	DMD
Naturally available (cont.)											
Syzygium cumuni	41.3	4.7	4.2	10.0	46.1	45.1	1.0	34.7	9.6	0.4	33.9
Terminalia arjuna	40.7	13.1	7.0	10.4	51.1	48.9	2.2	30.3	16.7	0.3	26.3
Thespesia populnea	29.3	11.6	5.0	18.7	30.8	30.4	0.3	26.1	1.9	1.5	38.0
Shrubs and creepers											
Canna indica	35.6	8.4	2.4	12.1	52.0	45.3	6.7	26.3	17.2	0.8	41.4
Cariss spinarum	36.2	6.9	3.1	13.1	64.7	52.7	12.0	30.8	20.4	0.6	29.0
Crotolaria juncea	29.6	5.5	4.3	14.7	43.4	35.6	5.6	21.3	13.6	0.6	54.8
Euphorbia heterophylla	23.2	10.9	2.8	22.0	22.2	13.8	8.5	11.0	2.2	0.3	75.9
Hibiscus furcatus	19.5	9.8	6.5	15.3	33.8	28.2	5.5	21.6	5.3	1.3	67.4
Hygrophyla spinosa	14.6	21.8	3.5	24.0	43.4	35.5	6.9	27.4	7.1	0.6	51.9
Loranthus nodiflorus	35.5	10.0	2.6	11.5	62.4	53.5	8.9	12.9	39.8	0.6	19.2
Memecylon rostratum	23.2	9.3	9.9	13.2	37.6	29.1	8.5	22.2	10.0	0.1	36.2

Note: DM, dry matter, CF, crude fibre; CP, crude protein; NDF, neutral-detergent fibre; ADF, acid-detergent fibre; H-cell., hemicellulose; Cell., cellulose; DMD, dry matter digestibility.

Tree fodders that are fed if available include cultivated tree crops for fruits or timber, grown on land owned by livestock farmers. The leaves of these trees are fed, if available, in the absence of common tree fodders. Nutritionally, these tree fodders could be considered satisfactory sources of nutrients (except *Mangifera indica*). Even though *M. indica* has a high dry matter content, its digestibility is low (40%) (Table 3). None of these tree fodders (fed if available) are a main source of fodder for goats.

Naturally available tree fodders have been collected mainly from the dry and intermediate zones of the country. They are used as supplements during feed shortages, mainly during the dry or very wet periods when the feed obtained by browsing or grazing is insufficient to satisfy nutritional needs. Nutritionally, *Adenanthera pavonina*, *Ceiba pentiandra*, *Ficus religiosa*, and *Grewia tilifolia* are satisfactory fodders sources, having digestibilities over 55% and fairly high levels of digestible crude protein (Table 3). Except for *A. pavonina*, *G. tilifolia*, and *Syzygium cumini*, the others contained more than 10% ash (Table 3), indicating that they are good sources of minerals. The low digestibility of most naturally available tree fodders is a limiting factor.

Shrubs and creepers are fodders commonly browsed by goats in the dry and intermediate zones of Sri Lanka. Their availability depends on the amount of uncultivated browse land available. Except for *Euphorbia heterophyllus*, *Hibiscus furcalus*, and *Solanum nigrum*, shrubs and creepers have a digestibility level less than 50% (Table 3). They are also poor sources of nutrients. The crude protein content of all these fodders is above 10%; however, the low digestibility of these fodders would yield low levels of digestible crude protein.

Use by agroclimatic zone

Dry zone

Goats are reared mainly in a browsing management system in the dry zone (Table 4). This is because of the availability of uncultivated shrubs in this area. Goats are stall fed during the wet period with the shrubs and tree fodders obtained from the land owned by the farmer or from outside. The main cultivated tree fodder used is *G. sepium*, which is grown along the fences of the farm lands.

Intermediate zone

The shrubs and tree fodders in the intermediate zone are similar to those in the dry zone. However, the methods of using these fodders for small ruminant production are different. This is mainly due to the availability of grazing facilities under coconuts. Apart from goats, fairly high concentrations of improved sheep are found in the intermediate zone. Unlike the dry zones, less facilities are available for browsing. Therefore, grazing, browsing, and stall-feeding are equally important management practices for rearing small ruminants in the intermediate zone (Table 4). Shrubs are browsed where uncultivated shrub jungles are available. Tree fodders are used where browsing and grazing lands are limited.

Table 4. Systems of feeding goats (%) by agroecological zone and status of land.

Feeding system	Zone		
	Dry	Intermediate	Wet
Grazed			
Owned	0	31	40
Not owned	0	25	20
Browsed			
Owned	89	36	9
Not owned	79	19	4
Stall fed			
Owned	20	29	74
Not owned	13	35	34
Browsed and staff fed			
Owned	18	16	7
Not owned	13	13	4
Grazed and stall fed			
Owned	0	16	36
Not owned	0	10	3

Source: Rajaguru and Senanayake (1987).

Wet zone

Contrary to the dry and intermediate agroecological regions, goats are mostly stall-fed in the hill, mid-country, and low country wet zones of Sri Lanka. *Gliricidia sepium*, *A. heterophyllus*, *E. variegata*, and *L. leucocephala* are the main cultivated tree fodder sources in the wet zone, according to order of importance. The first two are the most common sources of feed for goats, the other tree fodders are used in the different agroclimatic zones according to availability. Limited amounts of shrubs are fed to goats in these regions mainly because of the extremely limited browsing land.

Other factors influencing the use of tree fodders and shrubs

During the 1980s, expanding irrigation facilities and increased land use for various agricultural ventures have reduced the uncultivated browse lands in the dry and intermediate zones. This expansion is expected to bring 125 000 ha of land under irrigated agriculture in the dry zone, under the accelerated Mahaweli Development Programme, by 1990 (Sri Lanka 1986). Therefore, in these regions, the goat industry is changing from extensive to intensive or semi-intensive systems of management. Tree fodder production is increasing along fences and in uncultivated areas of farmers' holdings. Also, assistance from public- and private-sector organizations is available to farmers to change ruminant production into a more intensive system, integrated with crops.

There has not been much change in fodder production in the wet regions of Sri Lanka. In these regions, the land has been used extensively for plantation agriculture (tea, rubber, and coconut) and for the production of minor export crops such as black pepper, cloves, and nutmeg for the past few decades. The goat industry is expanding in these areas using fodder from *Gliricidia* and *Erythrina*, which are grown as shade and support for the high-income cash crops, such as black pepper, cloves, and tea. Assistance is also available in these areas in the form of loans and subsidies to increase pastures and fodders for livestock development.

Even though the importance of integrating fodders into forestry programs has been recognized, the progress achieved in this sector is extremely limited. There is no clear government policy for increasing the production of tree fodders and shrubs for livestock feeding. However, the emphasis given by the government to the expansion of lands under black pepper, cloves, and tea in the wet and intermediate zones will automatically increase the area under tree fodders used as shade and supports for these cash crops. In turn, this will lead to an increase in livestock and tree crop integration.

The average farm in Sri Lanka is around 1 ha. Therefore, a well-planned development program must compliment the establishment of improved, small sedentary herds within farm holdings, managed with the fodders produced within farmlands. Also, it is essential to evaluate the full potentials of commonly fed shrubs and tree fodders in small ruminant production systems. These considerations and a review of the limited information available suggest that Sri Lanka has great potential to improve its small ruminant industry by effectively using the wide variety of shrubs and tree fodders abundantly available.

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Availability and use of shrubs and tree fodders in Thailand

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Abstract *— Feed resources for livestock production in Thailand are becoming increasingly important because of rising costs and scarce supplies. It is, therefore, imperative to use fully the available feed resources, including unconventional supplies, to meet the rising demands of the rapidly increasing animal populations, especially during critical feed shortages. Crop residues, shrubs, and tree fodders are potentially important in small farms to alleviate shortages of feed and increase the efficiency of the production system. However, some of these feeds contain toxic elements that need to be reduced or removed before they can be fed to animals.*

Résumé *— Les espèces végétales utilisables comme fourrage dans la production animale deviennent, en Thaïlande, de plus en plus importantes en raison de la hausse des coûts et de la rareté des fourrages. Il s'impose donc d'utiliser pleinement ces espèces, y compris celles qui ne sont pas conventionnelles, pour répondre à la demande à la hausse attribuable aux populations animales en croissance rapide, surtout aux moments critiques de pénurie de fourrage. Les déchets agricoles, les arbustes et les arbres fourragers présentent un important potentiel, dans les petites exploitations agricoles, quant à la lutte contre les pénuries de fourrage et à l'accroissement de l'efficacité du système de production. Cependant, certains de ces fourrages contiennent des éléments toxiques qui doivent être réduits ou éliminés pour les rendre propres à la consommation animale.*

Resumen *— Los recursos alimenticios para la producción ganadera en Tailandia cobran cada vez mayor importancia debido al incremento de los costos y la escasez de oferta. En consecuencia, es imperativo usar completamente los recursos alimenticios, incluso los no convencionales, para satisfacer la creciente demanda, especialmente durante los períodos de escasez, de las poblaciones de animales que aumentan tan rápidamente. Los residuos de cultivos, los arbustos y los árboles forrajeros son potencialmente importantes en granjas pequeñas para mitigar la falta de alimento e incrementar la eficiencia y rendimiento del sistema de producción. Sin embargo, antes de dar al ganada estos alimentos, es necesario reducir o eliminar componentes tóxicos presentes en algunos de ellos.*

Agronomic characteristics and nutritive value

Several studies have been conducted to evaluate essential agronomic characteristics of potentially important shrubs and tree fodders. Because many parts of Thailand experience a long drought period, it is essential that the chosen species are able to withstand and produce adequate feeds in harsh environments. Sampet and Pattaro (1987) found that total edible dry matter (EDM) yield over 2 years among *Leucaena leucocephala*, *Sesbania grandiflora*, and *Gliricidia maculata* were significantly different and influenced yields (Table 1).

During the dry season, *L. leucocephala* grew better than *Sesbania* or *Gliricidia*. The nutritive values were quite good, especially for *Sesbania* and *Gliricidia* (Table 2).

The amino acid contents of *Mimosa pigra*, *L. leucocephala*, and *G. maculata* are comparable. All species are high in both essential and nonessential amino acids (Table 3).

Table 1. Edible dry matter (EDM) yields of *Leucaena leucocephala*, *Sesbania grandiflora*, and *Gliricidia maculata* with different cutting heights over 2 years.

Cutting height (cm above ground)	EDM yield (t/ha)			Mean
	Leucaena	*Sesbania*	*Gliricidia*	
		Year 1		
25	5.27	7.75	4.79	5.94
50	6.75	6.38	4.67	5.93
Mean	6.01a	7.01a	4.73b	
		Year 2		
25	10.68	2.48	4.85	6.00
50	12.07	3.30	5.39	6.92
Mean	11.38a	2.89b	5.12c	
		Total EDM		
25	15.95	10.23	9.64	11.94
50	18.82	9.68	10.06	12.85
Mean	17.39a	9.96b	9.85b	

Note: Values in the same row followed by the same letter are not significantly different at the 5% level.

Source: Sampet and Pattaro (1987).

Table 2. Chemical composition (% dry matter) of *Leucaena leucocephala*, *Sesbania grandiflora*, and *Gliricidia maculata* forage.

Species	Season	CP[a]	CF	Ash	OMD
L. leucocephala	Wet	25.2a	12.0	7.8	64.9
S. grandiflora	Dry		11.9	8.7	64.2
	Wet	29.1b	11.9	8.6	70.8
G. maculata	Dry		12.2	8.8	70.6
	Wet	27.8b	11.8	8.3	73.6
	Dry		11.6	9.9	74.1

Note: Values followed by different letters differ at the 5% level. CP, crude protein; CF, crude fibre; OMD, organic matter digestibility.

Source: Sampet and Pattaro (1987).

[a] The crude protein content is for both wet and dry seasons.

Table 3. Amino acid content (g/16 g N) of *Mimosa pigra*, *Leucaena leucocephala*, and *Gliricidia maculata*.

Amino acid	*M. pigra* leaves	*M. pigra* leaves and twigs	*L. leucocephala* leaves	*G. maculata* leaves
Essential				
Arginine	5.9	6.0	4.7	5.7
Histidine	2.8	2.8	1.9	2.4
Isoleucine	4.3	4.3	3.9	4.5
Leucine	8.0	8.3	6.7	7.9
Lysine	6.0	6.6	5.1	6.4
Methionine	1.8	1.8	1.2	1.5
Phenylalanine	7.7	5.5	4.3	5.6
Threonin	4.2	4.4	3.5	4.2
Valine	5.6	5.7	4.4	5.3
Nonessential				
Alanine	5.2	5.6	4.3	5.3
Asparagine	10.6	9.9	9.2	10.1
Cysteine	1.4	1.4	1.0	1.3
Glutamic acid	10.9	10.4	8.8	10.0
Glycine	4.7	5.0	3.9	4.7
Proline	4.9	5.2	4.9	5.0
Serine	4.5	4.3	3.7	4.2
Tyrosine	4.6	4.2	3.2	4.4

Source: Vearasilp et al. (1981).

Table 4. Dry matter yields (g/tree) of the edible fraction and woody stem, green leaf retention, and survival of forage trees at Khon Kaen, Thailand.

Species	Origin of seed	Yield of edible fraction (g/tree)	Yield of woody stem (g/tree)	Green leaf retention[a]	Survival (%)
Adenanthera pavonia	Western Samoa	399cd	64c	6.9	83
Albizia chinensis	Western Samoa	899c	1 180b	4.5	73
Albizia falcataria	Solomon Islands	1 960b	2 107ab	7.2	63
Albizia lebbek	Australia	781c	693bc	6.5	77
Calliandra calothyrsus	Western Samoa	320d	382c	3.2	13
	Indonesia	508cd	416c	2.6	30
Cassia siamea	Thailand	2 751a	3 304a	7.7	97
Enterolobium cyclocarpum	Indonesia	2 821a	2 727a	5.1	100
Gmelina arborea	Thailand	2 223ab	2 848a	2.0	83
Leucaena leucocephala cv. Cunningham	Australia	2 027ab	3 008a	5.6	100
Pithocellobium dulce	Thailand	244d	381c	6.7	90
Samanea saman	Solomon Islands	204d	46c	4.3	97
	Thailand	432cd	196c	6.7	100
Sesbania formosa	Australia	620cd	1 399b	4.2	7
Sesbania grandiflora	Thailand	305d	292c	3.5	0
Sesbania sesban	Australia	1 203bc	3 345a	2.4	0
Sesbania sesban var. *nubica*	Australia	1 417b	2 260ab	2.0	0

Note: Values followed by the same letter within a column are not significantly different at $P < 0.05$.

Source: Akkasaeng et al. (1989).

[a] Means of rankings taken in February 1985 and March 1986.

Table 5. Chemical composition (% dry matter basis) of the leaves at November (dry, H1) and May (wet, H2) harvests of forage trees at Khon Kaen, Thailand.

Species	Origin of seed	Ash		CP		NDF		IVDMD	
		H1	H2	H1	H2	H1	H2	H1	H2
Adenanthera pavonia	Western Samoa	4.7	4.3	16.7	17.9	43.5	42.8	66.9	64.3
Albizia chinensis	Western Samoa	3.4	4.1	28.0	22.6	71.8	68.6	53.3	50.7
Albizia falcataria	Solomon Islands	5.3	7.2	19.5	18.6	51.5	40.7	61.5	64.3
Albizia lebbek	Australia	6.6	8.0	28.8	22.1	46.4	44.2	54.5	64.5
Calliandra calothyrsus	Western Samoa	4.9	5.1	17.5	17.7	52.5	46.7	51.5	49.5
	Indonesia	4.7	5.2	14.0	15.8	44.5	48.4	44.5	45.7
Cassia siamea	Thailand	5.2	7.2	18.8	12.9	53.5	45.1	65.5	62.1
Enterolobium cyclocarpum	Indonesia	4.6	3.2	21.7	16.8	40.3	42.1	68.6	64.7
Gmelina arborea	Thailand	5.2	5.5	13.3	14.0	45.8	40.9	60.7	62.9
Leucaena leucocephala cv. Cunningham	Australia	5.7	9.3	19.7	20.6	47.8	51.2	52.7	62.2
Pithocellobium dulce	Thailand	4.8	6.4	19.1	22.4	49.2	43.6	59.6	68.2
Samanea saman	Solomon Islands	4.2	5.5	24.1	27.3	52.7	43.8	58.4	62.6
	Thailand	4.1	5.5	22.8	24.2	45.4	47.1	61.3	61.2
Sesbania formosa	Australia	7.2	5.7	21.5	20.8	50.8	45.4	57.9	54.8
Sesbania grandiflora	Thailand	4.8	7.5	26.5	13.6	45.1	37.1	66.9	66.4
Sesbania sesban	Australia	6.8	9.9	26.4	24.2	38.7	29.5	69.1	79.0
Sesbania sesban var. *nubica*	Australia	8.8	8.8	21.3	21.5	36.9	39.2	67.8	65.8

Note: CP, crude protein; NDF neutral-detergent fibre; IVDMD, in vitro dry matter digestibility.
Source: Akkasaeng et al. (1989).

Akkasaeng et al. (1989) studied the forage and fuelwood production of 17 provenances of predominantly leguminous shrubs and tree species (Table 4). When cut at 1 m height five times during a 30-month period, *Enterolobium cyclocarpum*, *Cassia siamea*, *Gmelina arborea*, and *L. leucocephala* gave the highest yields of edible material, with accumulated dry matter productions of over 2 kg/tree. *Sesbania* spp. and *Calliandra*, however, did not produce well in northeastern Thailand. The chemical composition of the leaves of all tested species was also reported (Table 5). Their crude protein (CP) and in vitro dry matter digestibility (IVDMD) percentages were relatively high, whereas the neutral-detergent fibre (NDF) contents were low, particularly for *Cassia siamea* and *Sesbania* spp. There appeared to be no differences between dry and wet seasons. In relation to potential importance and high nutritive values, more data is required on in vivo digestibility and intake by animals. The chemical composition of many other fodder tree species has been reported by Manidool (1985).

Use of shrubs and tree fodders

Some studies have reported on potentially important feeds with high nutritive values, summarizing their acceptance, intake, and use. Cow pea (*Vigna unguiculata*) crop residues at harvest are still fresh and contain an abundant proportion of green leaves. Both the leaves and stems are high in CP and easily digested in the rumen (Wanapat and Wachirapakorn 1986; Wanapat, Uriyapongson et al. 1989). When dried leaves were used to supplement rice straw for growing native cattle, a level of 300 g/head per day sustained body weight (Table 6). However, the residues can be used either green, dried, or as silage.

Table 6. Dry matter intake, digestible nutrient intake, and average daily weight change of native cattle fed rice straw supplemented with cowpea crop residue.

	Level of supplementation (g/day)				
	0	300	500	800	SE
Dry matter intake (kg/day)					
Rice straw	2.3	2.3	2.2	2.1	—
Cowpea residue	—	0.3	0.4	0.7	—
Total	2.3a	2.6a	2.6a	2.8a	0.1
Dry matter intake ($g/kg^{0.75}$)					
Rice straw	67.9	68.3	66.8	62.9	2.3
Cowpea residue	—	6.4	11.3	14.9	1.1
Total	67.9a	74.8ab	80.1b	77.8b	2.8
Digestible nutrient intake					
Dry matter (kg/day)	1.0	1.3	1.3	1.4	—
Crude protein (g/day)	—	48.6	60.2	124.4	—
Weight change (g/day)	−127.3a	11.2b	54.3b	24.9b	27.4

Note: Values in the same row followed by the same letter are not significantly different at $P < 0.05$. SE, standard error.

Source: Wanapat, Uriyapongson et al. (1989).

Another good forage supplement is cassava leaf. As reported by Bezkorowajnyj et al. (1986), the leaves can be collected from the bottom half to two-thirds of the plant, and as much as 469 kg fresh leaves or 156 kg dried leaves/ha can be produced without adversely affecting tuber yield. The leaves can also be collected every 60–75 days, and two collections can be made during the dry season, yielding 320 kg/ha of sun-dried leaves. Approximately 6 kg of fresh leaves (2 kg sun dried) can be collected in 1 h.

Fresh cassava leaves, however, contain high levels of hydrocyanic acid (HCN), which is toxic to animals. Sun drying the leaf (Fig. 1) reduces HCN content from

Fig. 1. A farmer sun drying cassava leaves (*Manihot esculenta*) for buffalo feed in Thailand.

210 to 31 mg% (Wanapat, Uriyapongson et al. 1989). Supplementing a low-quality roughage such as rice straw with dried cassava leaves maintained the body weight of both cattle (Bezkorowajnyj et al. 1986) (Table 7) and buffaloes (Wanapat 1983). Under village conditions, Wanapat, Uriyapongson et al. (1989) reported that supplementing dried cassava leaves to draft buffaloes during the dry season significantly improved both body condition and draft capability.

Mimosa pigra has been used in the diets of broilers, Japanese quail, and pigs at 4, 6, and 8%, respectively (Vearasilp 1988). In sheep, supplementing with fresh leaves of *M. pigra* at 400 g/head per day increased body weight at a rate of 350 g/head per day (Vearasilp et al. 1981). *Mimosa pigra* contains no mimosine; therefore, it is appropriate for ruminants. The digestion coefficients of nutrients in sheep fed *M. pigra*, have been reported.

Table 7. Dry matter intake and average daily weight change of cattle fed rice straw supplemented with cassava leaf (CL) and cassava chip (CC).

	Level of supplementation (g/day)					
	0	300 CL	600 CL	600 CC	300 CL 600 CC	600 CL 600 CC
Rice straw dry matter intake						
kg/day	2.8ac	3.2b	2.8a	2.1d	2.6c	2.8ac
% body weight	2.1a	2.2a	2.1a	1.7b	1.8b	1.8b
$g/kg^{0.75}$	72a	76a	71a	57c	61bc	64b
Total dry matter intake						
kg/day	3.1	3.7	3.6	2.9	3.7	4.2
% body weight	2.4a	2.6b	2.7bc	2.4a	2.5ab	2.7c
Weight change (g/day)	–181a	–108a	58b	–184a	–83a	59b

Note: Values in the same row followed by the same letter do not differ significantly at $P < 0.05$.

Source: Bezkorowajnyj et al. (1986).

Table 8. Performance of cattle fed rice straw supplemented with *Samanea* pods fed intact, water soaked, sodium-hydroxide (NaOH) soaked, ground, or with urea.

	Intact *Samanea* pods	Water-soaked pods	1% NaOH-soaked pods	Ground pods	Urea-supplemented pods (100 g/day)
Dry matter intake (kg/day)					
Samanea pod	1.8	—	5.6	2.6	5.9
Rice straw	2.1	—	1.7	1.4	1.9
Total	3.9	—	7.3	4.0	7.8
Digestibility (%)[a]					
DM	46.4	63.1	53.3	62.5	—
CP	28.7	48.2	53.4	46.5	—
CF	25.4	49.0	51.9	42.9	—
NFE	72.4	79.9	67.3	81.5	—
EE	11.0	24.0	38.5	36.1	—
Weight gain (g/day)	100.0	—	230.0	139.0	185.7

Source: Seetakoses et al. (1988).

[a] DM, dry matter; CP, crude protein; CF, crude fibre; NFE, nitrogen-free extract; EE, ether extract.

Studies using *Samanea saman* as feed have been receiving much attention because of the multipurpose nature of this species. Recently, *Samanea* pods have been reported to contain 12–19% CP and 14–20% crude fibre (CF) on a dry-matter basis (Seetakoses et al. 1988). The authors also reported that adding 2 kg *Samanea* pods to the rice straw diet of buffaloes enabled body weight to be maintained throughout the dry season. *Samanea* pods are, therefore, a good source of protein and energy with a rice straw diet. *Samanea* pods have a hard shell, however, which may contribute to its low digestibility. Thus, grinding, water soaking, sodium hydroxide, and urea treatments increase digestibility (Table 8).

Leucaena leucocephala leaves have been widely used in diets of all animal species. Cheva-Isarakul (1988) reviewed the use of leucaena as a feed. The available reports suggest that leucaena is degraded to some extent in the rumen and can by-pass it to the lower gut as a source of protein. Leucaena can produce ruminal NH_3 N coupled with volatile fatty acid (VFA) production (Wanapat et al. 1988). When used in diets, even at high levels, leucaena has had no serious detrimental effects (Snitwong et al. 1983). Leucaena can be fed fresh (Wongsrikeao and Wanapat 1986) or dried (Sarawish et al. 1988). Fresh leaves are more palatable and contain higher levels of protein, minerals, and vitamins, especially ß-carotene, compared with the sun-dried leaf. However, one important constraint of leucaena is its mimosine content, especially in the fresh leaves. Young leucaena leaves have a higher mimosine content than mature leaves (Table 9). Sarawish et al. (1988) demonstrated that supplementing the rice straw diet of growing native cattle with dried leucaena leaves produced good results; the results obtained with urea-treated rice straw were better. However, because of severe psyllid infestation, leucaena yield is insufficient, especially during the dry season. Therefore, other tree fodders must be investigated.

Tables 10 and 11 summarize results of nutritive studies and feeding trials in Thailand, respectively. It is evident that supplementing low-quality roughages such as rice straw with tree fodders and shrub leaves improves animal performance (Table 11). However, more research is needed to determine optimum supplementation levels, to obtain useful dose–performance responses, and to establish other feed mixtures that promote efficient utilization.

Table 9. Mimosine contents (%) of young and mature leucaena leaves collected from Pakchong and Roi-Et provinces in Thailand.

	Young leaves					Mature leaves				
Leucaena variety	**Feb.**	**Apr.**	**Jun.**	**Aug.**	**Mean**	**Feb.**	**Apr.**	**Jun.**	**Aug.**	**Mean**
Salvador type										
K-8 (Australian)	6.9	9.6	5.8	8.7	7.8	2.0	6.2	3.8	4.8	4.2
K-8 (Hawaiian)	11.2	8.7	7.8	9.1	9.2	2.6	3.8	4.2	6.7	4.3
K-28	3.7	9.3	7.0	7.7	6.9	1.6	5.6	4.1	4.4	3.9
K-67	9.3	6.3	8.0	6.7	7.6	4.9	4.0	4.6	4.5	4.5
K-156	3.4	5.0	5.8	6.7	5.2	1.9	3.5	4.0	4.3	3.4
cv. Peru	6.4	5.7	7.0	7.2	6.6	3.0	3.4	3.8	5.8	4.0
cv. Cunningham	2.5	7.8	8.7	8.0	6.8	1.3	1.3	5.1	4.5	3.0
Peruvian	5.5	6.8	7.8	7.7	6.9	1.8	3.3	4.8	4.8	3.7
Côte d'Ivoire	7.8	7.5	6.9	6.4	7.2	3.5	4.4	4.4	4.3	4.1
Mean	6.3	7.4	7.2	7.6	7.1	2.5	4.0	4.3	4.9	3.9

Source: Udom et al. (1982).

Table 10. Chemical composition and in vitro dry matter digestibility (IVDMD) (% dry matter basis) of selected tree fodders, shrub leaves, and crop residues in Thailand.

Feed	DM	CP	Ash	NDF	ADF	ADL	IVDMD
Samanea							
Leaves	89.5	22.4	3.3	37.0	32.1	16.1	—
Pods	89.0	16.7	3.3	—	—	—	—
Sesbania leaves	92.7	23.5	13.8	15.9	15.4	4.5	—
Cassava leaves	97.0	24.8	7.9	—	—	—	—
Sun hemp leaves	96.0	15.5	11.2	—	—	—	—
Water hyacinth							
Leaves	14.5	14.9	13.9	52.2	27.2	2.6	55.1
Leaves + stalks	8.9	9.2	14.8	51.6	31.0	2.9	52.8
Peanut residue							
Leaves	93.1	18.0	13.3	47.3	34.9	8.1	—
Stems	93.3	9.1	13.4	53.0	46.6	6.8	—
Cowpea residue							
Leaves	92.0	23.8	14.5	42.0	32.9	8.0	67.4
Stems	91.0	14.3	8.8	52.2	39.8	7.3	62.6

Note: DM, dry matter; CP, crude protein; NDF, neutral-detergent fibre; ADF, acid-detergent fibre; ADL, acid-detergent lignin.

Source: Wanapat (1986).

Table 11. Effects of supplementation of tree fodders and shrub leaf on rice straw intake and performance of ruminants in Thailand.

Ruminant species and diet[a]	Daily dry matter intake (head)[b]	Daily weight change (head)[b]
Crossbred Brahman cattle (91 days)		
RS + 1.5 kg dried kenaf leaf	2.5	248
RS + 2.13 kg cowpea hay	2.5	272
RS + 1.99 kg stylo hay	1.7	63
Grass silage	9.4	−204
Cattle (native) (120 days)[c]		
RS	2.9%	—
RS + sun hemp hay	2.7%	—
RS + sun hemp hay (3:1)	3.5%	—
RS + verano stylo hay (3:1)	3.3%	—
Sheep[d]		
RS + leucaena:gliricidia (1:0)	5.1	57.9%
RS + leucaena:gliricidia (1:1)	5.0	56.9%
RS + leucaena:gliricidia (1:2)	5.2	53.9%
RS + leucaena:gliricidia (1:3)	4.7	51.0%
Swamp buffaloes (30 days)		
RS + fresh leucaena	5.4	−440
UTS + fresh leucaena	6.3	444
Cattle (native) (133 days)[e]		
RS	63 g	−117
RS + 300 g DLL	70 g	−59
RS + 600 g DLL	79 g	41
UTS	80 g	−76
UTS + 300 g DLL	77 g	36
UTS + 600 g DLL	86 g	62

(continued)

Table 11. Concluded.

Ruminant species and diet[a]	Daily dry matter intake (head)[b]	Daily weight change (head)[b]
Cattle (native) (120 days)[e]		
RS	66.8 g	–114.6
RS + 300 g DCL	75.5 g	–56.6
RS + 600 g DCL	87.3 g	28.8
RS + 900 g DCL	94.1 g	63.4
UTS	69.9 g	3.4
UTS + 300 g DCL	78.7 g	52.6
UTS + 600 g DCL	85.9 g	84.0
UTS + 900 g DCL	91.9 g	146.4
Cattle (native) (113 days)		
RS	3.2	–60
RS + 1 kg *Acacia* pods	2.9	60
RS + 2 kg *Acacia* pods	3.9	100
RS + 3 kg *Acacia* pods	5.5	40
Cattle (native) (91 days)[c]		
RS	2.1%	–165
RS + 0.5 kg verano stylo hay	2.2%	11
RS + 1.0 kg verano stylo hay	2.2%	60
RS + 1.5 kg verano stylo hay	2.1%	104
Swamp buffaloes (123 days)[f]		
RS	5.1	–192, –375
RS + 1 kg dried *Mimosa* leaf	4.6	–103, –360
RS + 2 kg dried *Mimosa* leaf	3.7	–116, –326
RS + 3 kg dried *Mimosa* leaf	2.4	–9, –181
Swamp buffaloes (180 days)		
RS	—	64
RS + stylo	—	82
RS + sun hemp (2:1)	—	159

Source: Adapted from Wanapat (1986).

[a] RS, rice straw; UTS, urea-treated rice straw; DLL, dried leucaena leaves; DCL, dried cassava leaves.

[b] Except as noted.

[c] Daily dry matter intake is expressed as % body weight/head.

[d] Dry matter digestibility is listed instead of daily weight change.

[e] Daily dry matter intake is expressed as g/kg$^{0.75}$.

[f] Two values for daily weight change are given. The first is based on 2-year results; the second, 3-year results.

Recommendations

Given the potential importance of many shrubs and tree fodders as feeds, especially during the dry season, and in light of the current knowledge and rapid expansion and development of ruminant production in Thailand, particularly those of beef–dairy and buffalo production, the following recommendations are made concerning the more efficient use of shrubs and tree fodders.

- Potential species should be more widely planted in the farms to supply feeds throughout the year.

- These feed sources should be mainly used as supplements, especially with coarse roughages such as rice straw and other crop residues.
- Feeding strategies of available tree fodders and shrubs for relevant livestock-production systems and their production levels need to be identified.
- Potential varieties of shrubs and tree fodders need to be assessed regarding their values in the in vivo system.

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Availability and use of shrubs and tree fodders in Malaysia

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Abstract *— Only limited research has been undertaken on the availability, characterization, management, and use of indigenous fodder trees and shrubs in Malaysia for ruminant production. Some substantial studies have been undertaken on* Leucaena leucocephala *and* Cajanus cajan. *Feeding tree leaves to small ruminants, especially goats, as a supplement is a traditional practice of Malaysian livestock farmers. The various species used are usually found near the household, on vacant land, or in plantations. The intensity of using tree leaves and fodder shrubs is closely dependent on the type of management. The chemical composition of some common shrubs and fodder trees used by farmers in Malaysia is presented. The majority of fodder foliage is high in crude protein and crude fibre, and the minerals are adequate for livestock production. Information on productivity, intake, digestibility, and toxicity, however, is lacking. A farming-system approach for integrated fodder tree production in smallholdings is proposed.*

Résmué *— En Malaysie, trop peu de recherches ont été faites sur la disponibilité, la caractérisation, la gestion et l'utilisation d'arbustes et d'arbres fourragers indigènes dans la production de ruminants. Des études importantes ont porté sur* Leucaena leucocephala *et sur* Cajanus cajan. *Donner en complément de ration des feuilles d'arbre aux petits ruminants, surtout aux chèvres, est pratique traditionnelle chez les éleveurs de bétail malaisiens. Les espèces normalement employées se trouvent près de la ferme, sur des terrains vacants ou dans les plantations. Le degré d'utilisation des arbustes et des arbres fourragers dépend étroitement du type de gestion. L'auteur précise la composition chimique de certains arbustes et arbres fourragers dont se servent les paysans malaisiens. Presque toutes les feuilles de ces végétaux ont une haute teneur en protéines et en fibres brutes. Quant à leur teneur en minéraux, elle est suffisante pour la production animale. Manquent cependant des données sur la productivité, l'ingestion, la digestibilité et la toxicité. L'auteur propose une approche systémique pour intégrer la production d'arbres fourragers dans les petites exploitations agricoles.*

Resumen *— Solamente se ha emprendido una limitada investigación con respecto a la disponibilidad, caracterización, explotación y uso de árboles y arbustos forrajeros naturales de Malasia para la producción de rumiantes. Se efectuaron algunos estudios sobre* Leucaena leucocephala *y* Cajanus cajan. *Una práctica tradicional de los campesinos malasios es utilizar hojas de árboles como complemento alimenticio de rumiantes pequeños, especialmente cabras. Las diversas especies utilizadas se pueden encontrar comúnmente cerca de la casa, en terrenos vacíos o en plantaciones. La intensidad de uso de hojas de árboles y arbustos forrajeros depende en gran medida del tipo de explotación que se realice. Este trabajo presenta la composición química de algunos* *arbustos comunes y árboles forrajeros usados por los campesinos en Malasia. La mayor parte del follaje forrajero es rico en proteína y fibra en bruto y los minerales son adecuados para la producción de la ganadería. Sin embargo, se carece de información con respecto a la productividad, consumo, digestibilidad y toxicidad. Se propone un método de explotación agrícola para la producción integrada de árboles forrajeros en propiedades pequeñas.*

Introduction

In Malaysia a low-input, ruminant-production system is used in smallholdings. The animals feed on wayside forages, tree leaves, fodder shrubs, and crop residues in the field or in communal land. The wide variety of plant species provides a versatile source of forage managed either by a cut-and-carry system or by grazing. In addition, the ground vegetation in plantations totaling over 3.8×10^6 ha (Table 1) has the potential for ruminant production along an integrated farming–livestock approach.

The new national livestock policy emphasizes integrating livestock into plantations to increase livestock development, particularly with sheep. The natural undergrowth in plantations is mainly indigenous grasses, plantation legumes, broad-leaved plants, ferns, and other weeds (Wan Mohamed et al. 1987). Over 70% of the undergrowth can be used for grazing as its nutritive value is comparable to that of improved grasses (Wan Mohamed 1977). Exploiting this vast natural resource is the current priority in the ruminant industry of Malaysia.

Because of the large area of plantations in Malaysia, the agro-by-products derived from the major plantation crops (oil palm, rubber, and cocoa) are also abundant (5×10^6 t estimated). However, the use of these agro-by-products is not discussed in this paper, only feeds and feed materials from wayside shrubs and fodder trees are highlighted.

Tree leaves and shrubs in ruminant production

In Malaysia, fodder cultivation for livestock production is minimal because of the small livestock population and the year-round abundance of green feed. In other

Table 1. Projected dry matter (DM) productivity from native and cultivated forages in agricultural systems in Peninsular Malaysia.

Type of land	Area ($\times 10^3$ ha)	Average annual DM production (t/ha)	Total DM production[a] ($\times 10^3$ t)
Plantation land[b]	3 774.0	5	18 870.0 (79.1)
Grazing reserves	38.2	7	267.4 (1.1)
Cultivated forages[c]	25.0	20	500.0 (2.1)
Roadside pasture	6.3	7	44.1 (0.2)
Padi bunds	5.8	5	29.0 (0.1)
Marginal forests[d]	832.0	5	4 160.0 (17.4)
Total	4 681.3	—	23 870.5 (100.0)

[a] Percentages are shown in parentheses.
[b] Estimated one-third of land suitable for grazing.
[c] Government farms.
[d] Forest land for silviculture.

countries of Southeast Asia, fodder trees or shrubs are planted along roadsides, footpaths, the banks of rivers and canals, and rice field bunds to augment the poor-quality feeds available. Feeding tree leaves and fodder shrubs from nearby forest areas and marginal lands to ruminants is traditional in ruminant production, especially goats, in the humid tropics (Rahman 1981). Shrubs and tree fodders have an important nutritional role in village production systems as well as in areas where forage land is scarce. Usually, the fodder shrubs are fruit trees or legumes in the vicinity of the household, where they provide shade. However, there are few reported studies on the role of fodder trees and shrubs in production systems in Malaysia.

The use of tree leaves has several benefits:

- they provide variety to the diet;
- they serve as reserve foliage in times of drought;
- they meet energy, protein, and, possibly, mineral requirements;
- they maintain forage quality following maturity; and
- they reduce feeding costs.

The escalating price of feed ingredients, especially of preformed proteins, and the need to ensure that dietary proteins adequately supplement rumen microbial protein for production, have led to interest in the leaves of leguminous trees as a dietary nitrogen source (Devendra 1983).

Shrub and tree fodder species

Lim (1968) identified the types of fodders and feedstuffs used, determined their chemical composition, and assessed forage quality. Peters et al. (1979) conducted a survey in goat-production areas in Peninsular Malaysia and listed the tree species whose leaves have been fed to ruminants (Table 2). Besides the species listed in Table 2, *Flemingia congesta*, *Gliricidia sepium*, *Albizia falcataria*, and *Parkia speciosa* are grown as shade plants in cocoa plantations. Recently, *Calliandra calothyrsus* has been studied as a possible fodder supplier.

Proximate analysis of shrubs and tree leaves

In general, tree fodders and shrubs are high in crude protein and crude fibre (Table 3). Mineral levels are adequate in most cases for most classes of livestock. Also, the estimated metabolizable energy of the common fodder shrubs is as good as that of cultivated pasture if not better (Table 3).

Feeding fodder shrubs and tree leaves

The use of shrubs and tree leaves in Malaysia has not been adequately studied. Usually, it is the foliage that is eaten; sometimes, however, the stems or even the seeds are sought by the animals. Shrubs are used year-round in mixed grazing and

Table 2. Shrub and tree species used for fodder in Malaysia.

Fruit trees

Anacardium occidentale
Artocarpus heterophyllus
Artocarpus integer
Averrhoa bilimbi
Averrhoa carambola
Eugenia aquea
Ficus spp.
Mangifera indica
Morinda citrifolia
Musa sapientum
Nephelium lappaceum
Sandoricum koetjape

Palm

Cococ nucifera
Elaeis quianeensis

Tall trees

Fragraea fragans
Callicarpa tomentosa
Grewia paniculata
Hevea brasiliensis
Terminalia catappa

Shrubs

Bridelia menoica
Carallia spp.
Cinnamomum iners
Clausena excavaeta
Flemingia spp.
Gliricidia sepium
Greenea corymbosa
Leucaena leucocephala
Macaranga indica
Manihot esculenta
Moringa oleifera
Sesbania grandiflora
Vitex pubescens

Source: Adapted from Peters et al. (1979).

Table 3. Proximate analysis (% dry matter basis) of some shrubs and tree leaves used in ruminant production.

Species	DM (%)	CP	CF	EE	Ash	Ca	P	ME (MJ/kg DM)
Anacardium occiaentale	28.8	9.9	27.4	1.5	3.3	—	—	9.8
Artocarpus heterophyllus	36.6	19.1	17.4	4.1	8.3	1.38	0.16	13.2
Artocarpus integer	35.3	13.1	17.5	2.6	7.0	1.05	0.10	12.2
Averhoa carambola	32.6	15.3	14.4	3.9	7.0	1.46	0.16	13.2
Bridelia monoica[a]	38.5	7.5	28.9	3.3	4.4	0.83	0.10	9.1
Cajanus cajan	90.0	21.7	30.2	6.0	6.0	0.85	0.26	—
Carallia spp.	30.9	5.5	25.8	3.8	6.0	—	—	9.3
Cinnamomum iners	—	—	36.4	2.5	3.1	0.32	0.17	—
Cocos nucifera[b]	40.8	10.9	22.1	4.4	4.7	0.54	0.04	10.9
Elaeis guineensis[b]	39.0	16.4	23.0	5.0	8.1	0.44	0.03	11.7
Eugenia aquea	—	11.5	24.0	2.5	5.1	0.95	0.15	10.7
Ficus fistosa	19.6	14.0	15.1	1.9	11.7	2.47	0.24	12.8
Fagraea fragrans	35.3	11.4	25.5	4.3	2.9	0.03	0.04	10.4
Grewia paniculata	—	13.2	28.1	2.0	8.6	1.96	0.08	10.2
Macaranga indica[a]	35.8	11.1	25.2	3.2	8.4	0.88	0.06	10.4
Mangifera indica	46.3	10.4	21.0	6.0	6.3	1.63	0.12	11.1
Manihot esculenta	90.0	25.0	15.9	6.3	5.5	1.40	0.25	—
Nephelium lappaceum	30.6	15.0	24.5	2.6	4.9	0.99	0.24	11.2
Vitex pubescens[a]	38.6	15.0	28.5	1.5	4.4	0.52	0.13	10.5

Note: DM, dry matter; CP, crude protein; CF, crude fibre, EE, ether extract; ME, metabolizable energy.

[a] Source: Rahman and Khusahry (1984).

[b] Source: Devendra (1979a), Rahman et al. (1985).

the intensity of use of tree leaves and shrubs depends greatly on the system of ruminant management. There are four general systems of management adopted by smallholders:

Table 4. Management systems of farmers (%) using tree leaves.

	Type of feed in the shed			
Management system	**Natural vegetation**	**Leaves**	**Salt**	**Concentrate**
Intensive	100.0	69.7	72.7	9.1
Semi-intensive	5.4	41.9	73.0	8.1
Tethering	0.0	58.3	75.0	8.3
Estate semi-intensive	6.9	44.8	79.3	6.9
Total	28.3	49.3	74.3	8.1

Source: Adapted from Peters et al. (1979).

- *Intensive*: Animals are totally confined to a shed and cut-and-carry feeding is practiced.
- *Semi-intensive*: Animals are let out for grazing for a restricted period, usually in the afternoon, and confined to the shed at night and in the morning.
- *Tethering*: Animals are kept in the shed at night; during the day, they are tethered along the roadside, on public grounds, or in the vicinity of the houses.
- *Extensive*: Animals are kept on free range day and night.

In the intensive system, cut forage is given once or twice a day ad libitum. In the semi-intensive system, the animals are let out to graze for 3–6 h and cut forage including fodder shrubs or tree leaves is given in the evening for night feeding.

Leaves of different trees, shrubs, and other plants are fed to the goats by 49.3% of goat farmers (Table 4). This practice is mainly found in intensive management (69.7%). Leaves are mainly supplied to does after kidding to boost milk production. Leaves of cassava (*Manihot esculenta*) are given by 42.5%, leaves of jackfruit (*Artocarpus heterophyllus*) by 30.1%, and leaves of mengkudu (*Morinda citrifolia*) by 15.1% of goat keepers. Other species are given in small amounts. Leaves are given either daily or at intervals of several days. However, the quantity and quality of the tree leaves fed to the goats are unknown. Concentrates generally fed to goats also contain tree leaves.

Information on the productivity of lesser known shrub species is largely lacking. Quantitative data is limited partly because of the lack of adequate techniques in browse yield estimation and partly because of the diversity of plant species and the arbitrary and subjective quantities used in feeding. Nevertheless, agronomic studies on some commonly known fodder shrubs, such as *L. leucocephala*, *Cajanus cajan*, and *Gliricidia sepium*, have been undertaken (Wong et al. 1984; Wong and Sharudin 1986; Wan Mohamed and Ravoof 1987).

Agronomic research

Some research has been done assessing and comparing the performance of tree species in Malaysia. Normally, the selected species are based on recommendations or published work in other countries.

Table 5. Nutritive value of leucaena (*Leucaena leucocephala*) and pigeon pea (*Cajanus cajan*) for sheep and goat.

	Leucaena		Pigeon pea	
	Goat	Sheep	Goat	Sheep
Digestible crude protein (%)	10.2	9.6	11.9	9.1
Total digestible nutrients (%)	57.4	50.5	52.9	40.7
Digestible energy (MJ/kg)	10.6	9.3	13.4	9.8
Metabolizable energy (MJ/kg)	8.8	8.0	11.0	8.0

Source: Devendra (1982).

Leucaena leucocephala

Leucaena is either planted or grown naturally in the countryside. The plant had been cultivated to provide shade for coffee in the early 1930s, but had not been extensively adopted. Interest in leucaena as a source of high protein feed was renewed after the problems of establishment were overcome through proper liming and inoculation of seed with effective *Rhizobium* strains (Tham et al. 1977). Leucaena has been a source of dietary protein to ruminants (Table 5) and xanthophyll pigment for poultry feed (Devendra 1982; Vadiveloo 1985).

Wong et al. (1984) obtained a dry matter yield of 13–22 t/ha per year from selected varieties at 8-week cutting intervals and at 50–100 cm cutting height. Grazed cattle in a grass–leucaena mixture gave daily live weight gains of over 400 g/head (Wong and Devendra 1983). When indigenous goats were supplemented with leucaena to varying levels of dried palm oil mill effluent, the quality of the total diet improved, resulting in higher intakes and live weight gains (Vadiveloo 1985).

Leucaena can be supplemented up to 30 g/kg live weight with goats fed dried palm oil effluent with no detrimental effects. Successful cultivation of leucaena as a high-protein crop has made leucaena leaf meal production in Malaysia a possibility. Malaysia annually imports over 48 000 t of leaf meal, at an estimated cost of over 8×10^6 USD, for pigs and poultry feeds. In various commercial feeds, imported leaf meal ranges from 2 to 5%. The importance of substituting leucaena leaf meal for imported leaf meal is illustrated in Table 6. The importance of producing leucaena leaf meal locally has been stressed (Mustaffa 1987).

The milk productions of Sahiwal-Friesian cows under stall feeding and rotational grazing on leucaena–*B. decumbens* pasture were 7 090 and 8 580 kg/ha per lactation, respectively (Wong et al. 1987). No nitrogen fertilizer was used in the pasture mixture.

The major constraint in promoting leucaena is its severe defoliation as a result of psyllid infestation. This is especially prevalent during dry periods. The Malaysian Agricultural Research and Development Institute (MARDI) is trying to develop new, superior, acid-tolerant leucaena hybrids with a high degree of psyllid resistance.

Gliricidia sepium

Gliricidia is a relatively fast-growing tree and is now common in plantations as a nurse tree. It is a deep-rooted perennial and provides a valuable, high-protein, green

Table 6. The effect on egg production and quality of different levels of leucaena leaf meal in the diet of poultry layers.

	Leucaena leaf meal (% dry matter)			
	0[a]	3[b]	6[b]	9[b]
Egg production	68.0	72.0	67.7	67.3
Avg egg weight (g)	60.9	61.4	60.3	61.9
Total egg mass (kg)	11.2	12.0	11.2	11.2
Total feed intake (kg)	29.8	30.2	29.9	29.2
Daily feed intake (g)	100.1	110.0	109.5	107.3
Feed: egg mass ratio	2.68	2.53	2.69	2.63
Albumin height (mm)	6.42	6.13	6.49	6.52
Haugh unit	77.9	75.6	78.4	29.0
Yolk colour index	6.9	7.8	9.8	11.6
Shell thickness (mm)	0.389	0.389	0.383	0.381

Source: Yeong (1988).

[a] Control diet containing 30% yellow maize.

[b] Treatment diets using broken rice to replace yellow maize.

feed supplement (25–30%), especially for small ruminants. In Malaysia, gliricidia is grown as a shade tree and as an ornamental in the house compound. It can withstand lopping up to 1–1.5 m cutting height without damaging regrowth. However, the tree tends to shed its leaves at the onset of a dry spell and at the blooming stage. The plant has not been exploited for fodder production, although information is abundant on its cultivation as a shade plant in cocoa plantation (Wills 1980).

Preliminary studies on gliricidia as a fodder plant by Wong and Sharudin (1986) have not been encouraging. Stem cuttings grew poorly and dry matter productivity was poor compared with the fast-growing leucaena and cassava. Annual dry matter yield of gliricidia is about 2 t/ha. Heavy infestation of an insect pest (*Brachyplatys* spp.) was observed at certain times of the year. In vitro dry matter digestibility, nitrogen content, and mineral concentrations of the foliage were comparable with those of cassava and leucaena. Because of its availability as a shade plant in cocoa plantation, it has forage potential in integrated systems. More research is needed on using existing gliricidia in cocoa plantations for small ruminant production. The germ plasm of gliricidia should be expanded to assess suitable foliage types for the humid tropics.

Cajanus cajan

The use of *Cajanus cajan* (pigeon pea) in Malaysia as a forage plant is a recent phenomenon. The plant is never cultivated on a commercial scale or at the smallholders' level. However, Wan Mohamed and Ravoof (1987) reported an annual dry matter production of 3.7–9.8 t/ha with an annual crude protein yield of 0.8–1.3 t/ha from 6- to 8-week cutting frequencies. The optimum planting distance was 30 × 61 cm and the nitrogen fertilizer rate was 55 kg N/ha per year. Crude protein content ranged from 25 to 28%; crude fibre, from 22 to 24%. More than 15% pigeon pea leaf meal in the feed of broiler chickens was detrimental (Table 7).

Beneficial use of pigeon pea foliage by sheep and goats was illustrated by Devendra and Chee (1980). The results consistently demonstrated the superiority of goats over sheep using pigeon pea fodder. An estimated 300 kg N/ha per year was

Table 7. Performance of broilers fed pigeon pea leaf meal.

Growth attribute	% pigeon pea leaf meal				
	0	7.5	15.0	22.5	30.0
Initial body weight (g)	361	435	439	440	427
Body weight at 9 weeks (g)	1 708	1 683	1 599	1 445	1 105
Total feed intake (g)	3 775	3 966	3 625	3 614	3 240
Feed/gain	3.0	3.0	3.1	3.6	4.8
Mortality (%)	31.6	25.6	21.8	21.0	10.4
Avg final weight (g)	1 710	2 260	1 600	1 430	1 120

fixed. More studies are needed to assess the potential of pigeon pea as a forage crop in humid environments because the plant is more adapted to semi-arid conditions.

Other species

Little work has been done on the other shrubs and fodder trees listed in Table 2. Nevertheless, livestock farmers use them as fresh fodder supplements for their animals. These plants are generally not cultivated, they thrive as weeds near forest margins or in neglected, cleared areas.

Toxicity problems

Many shrubs and trees in Malaysia are not used in ruminant production both because of a lack of knowledge and because of the possible presence of toxic compounds. Causes of toxicity are poorly understood and vary from species to species. For example, cassava foliage can contain prussic acid, which, when consumed in large quantities, can kill the animal (Jaafar 1982). However, there is no clear evidence of such poisoning in certain districts of Malaysia, such as Banting Kuala Selangor and Sabah Bernam of Selangor Darul Ehsan (Rahman et al. 1985).

Similarly, leucaena contains mimosine, whose by-product, dihydroxypyridine (DHP), is toxic to monogastric animals and can cause enlarged thyroid glands and alopecia in ruminants if consumed in large quantities. In Malaysia, no obvious adverse effect of leucaena on ruminants had been recorded except at very high levels under experimental conditions (Devendra 1982). Nevertheless, cattle grazing on leucaena–signal grass mixture had slightly enlarged thyroid glands but no external symptoms of toxicity (Izham and Hassan 1984). Recent studies at MARDI showed, however, that goats in Malaysia were unable to degrade DHP because of the absence of the mimosine–DHP degrading bacteria in the rumen (Wong et al. 1989). The DHP in the urine of goats increased with increasing levels of leucaena in the diet.

In contrast, Vadiveloo (1985) observed no toxicity from mimosine when goats were fed 100% leucaena. Such a diversity of responses deserves investigation. Because little research has been done on local tree leaves and fodder shrubs as forage supplements in ruminant production, more research is needed to identify nontoxic or less toxic species for use in the future.

Research strategies

Currently, fodder shrubs are underused, partly because of the abundance of other natural feed resources. Also, little is known of their nutritional value. A systematic study of available shrubs and fodder tree leaves involving a nationwide survey is needed. Species must be characterized and their feeding value in raw and processed forms must be evaluated. Beneficiaries must be identified and existing farming systems and systems of economic production must be described. This is probably the most relevant strategy to promote the use of tree leaves and realize achievable, profitable levels of ruminant production.

In this respect, tree leaves and shrubs should be regarded as proteinaceous, mineral supplements, providing critical nutrients to deficient basal diets (Leng 1985). They will enhance efficient fermentative digestion and correct any nutrient imbalances in the animals, preparing them for demanding physiological states such as lactation. The criteria for using tree leaves as a supplement will be governed by the nutrients that are deficient in available feed resources.

Effective research to enhance nutritive value may follow. Physical, chemical, or biological treatments that are economically justifiable and applicable to small farms must be developed. Finally, appropriate environmental management and production systems should be developed (e.g., integrating fodder shrubs into cropping systems or intensive feed gardens).

Conclusions

Few trees or shrubs are used for livestock production in Malaysia. Despite the abundance and diversity of plant species in the country, their potential is poorly understood. Undoubtedly, many more species must be identified and studied before they are accepted as forage supplements.

In Malaysia, land and production inputs are the major constraints on forage development. The use of indigenous fodder shrubs and tree leaves, coupled with available, cheap, nonconventional feed resources, could be instrumental in fulfilling the forage and feed requirements of ruminants in the future.

The use of shrubs and tree fodders will eventually be linked to stimulating and expanding the country's ruminant livestock industry. Hence, the success of shrub and tree fodder research rests primarily in its applicability and potential to service the needs of the small-scale livestock producer.

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Availability and use of shrubs and tree fodders in Indonesia

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Abstract *— Shrubs and tree fodders have traditionally been included in livestock diets in Indonesia. Leucaena is the most extensively used. Although such feed is abundant, it is still underused. The Indonesian government funds and popularizes feed plants for many purposes throughout the country. Marked progress has been made in using shrubs and tree fodders as animal feeds, but more remains to be done. The success and effectiveness of a campaign to popularize plants as animal feed depend largely on extension services. This paper highlights the campaign, supported by the government, to promote the growth and use of shrubs and fodder trees in Indonesia.*

Résumé *— Les arbustes et arbres fourragers ont toujours été incorporés à la ration alimentaire du bétail en Indonésie. Le leucaena est l'arbre le plus communément employé à cette fin. Bien que ce type de fourrage soit abondant, il reste sous-exploité. Le gouvernement indonésien finance, dans tout le pays, la plantation et la vulgarisation de plantes fourragères à diverses fins. De grands progrès ont été réalisés dans l'emploi des arbustes et des arbres fourragers, mais il reste encore beaucoup à faire. Le succès d'une campagne de vulgarisation de plantes à employer comme fourrage dépend en grande partie des services de vulgarisation. Les auteurs donnent les points saillants de la campagne, financée par le gouvernement, pour promouvoir la culture et l'emploi d'arbres et d'arbustes fourragers en Indonésie.*

Resumen *— Los arbustos y rboles forrajeros han sido incluídos tradicionalmente en los regímenes alimentarios de Indonesia. Leucaena es la especie utilizada más ampliamente. Aunque dicho forraje es abundante, aún se usa insuficientemente. El Gobierno de Indonesia subvenciona y difunde el uso, con diferentes y múltiples propósitos, de plantas forrajeras en todo el país. Se ha adelantado bastante en la utilización de arbustos y árboles forrajeros como alimento animal, pero aún resta por hacer. El éxito y la eficacia de una campaña destinada a promover el uso de plantas como forraje dependen en gran medida de los servicios de extensión agrícola. Este trabajo destaca la campaña, que cuenta con apoyo gubernamental, para promover el cultivo y uso de arbustos y árboles forrajeros en Indonesia.*

Introduction

Indonesian farmers have long been feeding shrub and fodder tree leaves to animals (Table 1, Fig. 1). The leaves are usually fed fresh in a cut-and-carry system

Table 1. Some plants used as animal feed in Indonesia.

Species	Location	Source
Acacia leucocephoaea	Timor	Drees (1950), Piggin and Parera (1984)
Albizia falcataria	West Java	Lowry et al. (1983)
Anacardium occidentala	Timor	Drees (1950)
Antidesma hunii	West Java	Lowry et al. (1983)
Artocarpus heterophyllus	West Java, Timor, Bali	Drees (1950), Sabrani et al. (1982), Lowry et al. (1983), Panjaitan and Blair (1984), van Eys et al. (1984)
Bauhinia malabarica	Timor	Drees (1950)
Calliandra callothyrsus	West Java, Bali	Lowry et al. (1983), Panjaitan and Blair (1984)
Ceiba pentandra	West Java, Timor	Drees (1950), Lowry et al. (1983), van Eys et al. (1984)
Clidemia hirta	West Java	Lowry et al. (1983)
Datura fastuosa	West Java	van Eys et al. (1984)
Erythrina sp.	West Java, Bali	Panjaitan and Blair (1984), van Eys et al. (1984)
Ficus sp.	Timor	Drees (1950)
Flemingia congesta	—	Personal observation
Gliricidia maculata	West Java, Timor, North Sumatera	Drees (1950), Lowry et al. (1983), Mawi et al. (1987), Sukardi et al. (1988)
Hibiscus rosasinensis	West Java	van Eys et al. (1984)
Hibiscus tiliaceus	West Java	van Eys et al. (1984)
Kayu santen (local)	Bali	Panjaitan and Blair (1984)
Lantana camara	Timor	Drees (1950)
Leucaena leucocephala	West Java, Timor, Bali, Yogyakarta, Central Java	Drees (1950), Lebdosukojo et al. (1979), Siregar (1981), Sabrani et al. (1982), Panjaitan and Blair (1984), Piggin and Parera (1984), van Eys et al. (1984)
Maesopsis emenii	West Java	Lowry et al. (1983)
Melastoma malabathricum	West Java	Lowry et al. (1983)
Mangifera indica	West Java	van Eys et al. (1984)
Nephelium lappaceum	West Java	Lowry et al. (1983)
Persea americana	West Java	Lowry et al. (1983), van Eys et al. (1984)
Schleichere oleosa	Timor	Drees (1950)
Sesbania grandiflora	West Java, Timor, Bali, Yogyakarta	Drees (1950), Lebdosukojo et al. (1979), Sabrani et al. (1982), Panjaitan and Blair (1984), Piggin and Parera (1984), van Eys et al. (1984)
Sesbania sesban	—	Personal observation
Tamarindus indica	Timor	Drees (1950), Piggin and Parera (1984)

Fig. 1. An Indonesian farmer carrying harvested, mixed tree fodders to feed to his ruminants.

and are mostly of high quality because of their high crude protein content (Table 2). Among the plants listed in Table 1, *Leucaena leucocephala* is the most popular because of its wide distribution, availability, and use by farmers. This is followed by *Sesbania grandiflora*, *Gliricidia sepium* and *Calliandra callothyrsus*.

The plant species, especially leucaena and gliricidia, consist of many cultivars and have different local names. Often, there is more than one name for the same plant in the same region (see Bimantoro 1976; Siregar 1981).

Shrub and fodder trees are of national importance: they can benefit not only farmers but also nonfarmers. Several new cultivars have been imported to the country during the last two decades. Some of them are being tested and studied in a number of research institutions and some have already reached the farmers.

Availability and distribution

Leucaena leucocephala

Leucaena is the most widespread fodder species, found throughout the country. It is planted on forest lands, garden fences, along the banks of the ditches, and along roadsides. The species serves many purposes such as providing green fertilizer and shade for estate crops (coffee, vanilla, pepper, cocoa, and others). It also controls erosion and is a source of firewood, timber, food, and animal feed.

Spacing between plants varies depending on the needs of the species and the purposes of growing the plant. Usually, leucaena is planted in rows. For soil conservation on terraced lands it is planted at 1 × 1 m spacing. In estate plantations, the spacing may range from 3 × 3 m to 6 × 6 m. In a coffee plantation in Sumbawa

Table 2. Composition of some shrub and tree fodders (% dry matter basis) fed to livestock in Indonesia.

Species	CP[a]	NDF[a]	Ash	Ca	P
Albizia falcataria	24	37	7	1.4	0.1
Antidesma hunii	15	31	14	1.7	0.2
Artocarpus heterophyllus	15	32	12	1.6	0.2
Calliandra callothyrsus	24	24	8	1.6	0.2
Ceiba pentandra	12	21	20	6.0	0.2
Clidemia hirta	11	30	8	1.6	0.2
Maesopsis emenii	26	20	5	0.6	0.2
Melastoma malabathricum	13	31	10	2.2	0.1
Nephelium lappaceum	9	35	5	1.3	0.2
Persea americana	11	32	5	1.2	0.2
Gliricidia sepium	27.3	52.1	6.6	1.58	0.29
Leucaena leucocephala	19.7	51.5	11.5	2.56	0.22
Sesbania grandiflora	25.8	31.5	8.4	2.20	0.28

Source: For *G. sepium*, *L. leucocephala*, and *S. grandiflora*, Mathius et al. (1984); for all others, Lowry et al. (1983).

[a] CP, crude protein; NDF, neutral-detergent fibre.

it was found that besides the usual spacing, the spacing between plants in the rows was so small, due to regrowth of the seeds originally planted, that a goat could hardly pass between them. It was apparent that the rows were not only to provide shade but also to break the wind, provide green fertilizer, and control erosion.

Some existing cultivars are native to Indonesia. They adapt well to the local environments, but most of them are slow growing and produce less leaves and wood than the exotic cultivars. Because many of the exotic cultivars have already reached farmers, it is possible to find many different cultivars in the same fence, especially in Java.

Leaf production of leucaena varies according to factors such as cultivar, locality, environment, cutting height, cutting interval, and spacing between plants. Semali (1984) reported that extending the cutting interval from 4 to 16 weeks increased the production of fresh and dry matter (DM), but decreased the crude protein and phosphorus contents of the leaves. The proportion of leaves also decreased from 69% at 4 weeks to 40% at 16 weeks cutting interval.

Piggin and Parera (1984) reported that the annual fresh leaf production of leucaena in East Nusa Tenggara was 11.6, 11.1, 9.3, 7.6, and 2.6 t/ha for K6, K8, K28, K67, and the local varieties, respectively. Siregar (1983) reported fresh leaf production of 113.7 t/ha in Bogor at 1 m cutting height with a plant density of 10 000 plants/ha.

The most extensive cultivation of leucaena was found in East Nusa Tenggara. Piggin and Parera (1984) reported there was 50 000 ha of leucaena plantations in Amarasi (West Timor) and 27 000 to 43 500 ha in Sikka (Flores) in 1982. Siregar (1981) reported that more than 2 million leucaena seedlings were planted in Madura on more than 200 ha of land.

Siregar (1981) reported that from Gundih, Telawa, and Purwodadi (Central Java), and Tangen and Ngawi (East Java), in teak forests alone, 7 788.2 t of leucaena meal, equivalent to 23 500 t fresh leaves, was collected during

1977–1979. Silitonga (1985) estimated that the DM production of the Hawaiian-type leucaena was 762.3 t/year for East Java.

The production of leucaena leaves is indeed enormous, but reliable data on its total production for Indonesia is not available. Leucaena forage is particularly important to farmers in Java, Madura, Bali, West Nusa Tenggara, and East Nusa Tenggara, which has most of Indonesia's livestock and, where, during the dry season, forage is often in short supply.

Sesbania grandiflora

Sesbania grandiflora has long been promoted by the government as a multipurpose plant. It provides flowers, trunks for firewood, construction, and pulp, and leaves for human and animal feed. It is a popular plant, but cannot stand repetitive cutting: the plant dies out after the fourth or fifth cutting. To overcome such a characteristic and to collect leaves for a longer period, farmers use the lopping system. They cut the lowest branches first, followed by the higher ones as the plant grows.

Sesbania sesban

Sesbania sesban is another plant often fed to animals, but its distribution is limited. It is only found in some parts of East Java and very rarely in other parts of the country.

Calliandra callothyrsus

Calliandra callothyrsus is another potentially important source of feed. It is an exotic plant imported from Guatemala for reforestation, soil conservation, erosion control, and firewood production. Suyono (1975) reported that the Indonesian Forestry Authority imported seed of *Calliandra callothyrsus* (red flowered) and *Calliandra tetragona* (white flowered) in 1936 and 1939. In 1940, the white-flowered calliandra was severely infected by red root fungus (*Gonoderma ferrugecum*). Its susceptibility to this disease, as well as other characteristics, excluded *Calliandra tetragona* from further development. Since then, only the red-flowered calliandra has been developed.

Suyono (1975) reported calliandra forests of about 2 000 ha in East Java and that the people of Toyomerto (Malang), in 1965, possessed 240 ha of forested calliandra fields with 1 × 1 m spacing between plants. Satjapradja and Sukandi (1981) reported that the cultivated area belonging to the people of Toyomerto (Malang) was 270 ha. The dry weight leaf production of this area was 10.2 t/ha per year (Siregar 1983). For East Java, the dry leaf production was estimated at about 116 000 t/year (Silitonga 1985).

In other parts of Java, calliandra is found in forests and in fences around agricultural lands. Its potential as an animal feed is not as well known as that of leucaena or *Sesbania grandiflora*.

Gliricidia sepium

Gliricidia sepium is another potentially important species for feed production in Indonesia. It is rapidly gaining popularity and some new cultivars have been introduced and are being studied intensively for their adaptability, production, and use as feed. Ella et al. (1988) reported that delaying the first cutting from 13 to 21 months of age increased both the production and DM yield of the leaves at the first cutting. Siregar (1985) reported the annual dry weight leaf yield of gliricidia was 23.21 t/ha. Silitonga (1985) estimated the DM yield of gliricidia leaves at 53 002 t/year for East Java.

Others

Fodders from hibiscus, acacia, and artocarpus also contribute to the total national feed supply. They are fed to livestock only rarely, as they are not easily available to most farmers.

Use and feeding practices

The use of shrub and tree fodders is becoming increasingly important in Indonesia. Using agricultural land for home and plant construction reduces the availability of natural forage for livestock. Also, increasingly intensive crop farming reduces the grazing frequency of the animals. All of this forces farmers to look for alternative sources of feed. Although intensive crop farming makes more straws available, farmers have to look for other protein-rich feedstuffs to satisfy the needs of their animals. The choice then falls to shrub and tree fodders.

Farmers judge the value of any feedstuff before they feed it to their animals (Mawi et al. 1987). They have fed shrub and tree leaves to cattle (Lebdosukojo et al. 1979; Siregar 1981; Piggin and Parera 1984; Thalib and Siregar 1984), dairy cattle (Siregar 1981), sheep and goats (Drees 1950; Siregar 1981; Sabrani et al. 1982; Panjaitan and Blair 1984; van Eys et al. 1984; Mawi et al. 1987; Sukardi 1988), and pigs and chickens (Siregar 1981; Piggin and Parera 1984).

In Java, sheep and goats are sometimes fed only on leucaena and *Sesbania grandiflora*. This usually happens only when the animals cannot be taken out to graze for various reasons. In West Java, feed is put in the troughs in the animal feed pens. In East and Central Java, where the animals are housed in a shelter with a soil-compacted floor, the feed is tied to ropes and hung so that even the shortest animal can reach it. This practice prevents the feed from being contaminated with urine, feces, or dirt from the soil.

The amount of feed fed to animals varies according to species, locality, and season. Lebdosukojo et al. (1979) reported that farmers in Playen and Cangkringan (Yogyakarta) fed leucaena and *Sesbania grandiflora* forage to as much as 19.6% of the diet. In Amarasi (Timor) (Piggin and Parera 1984), farmers fed their Bali cattle as much as 15–20 kg/head leucaena fodder daily; banana stems were offered as an additional feedstuff. This feeding regime produced daily live weight gains of about 0.45 kg/head in fattened Bali cattle (Thalib and Siregar 1984).

In a baseline survey in three selected locations in West Java, representing low, medium, and high altitudes, Sabrani et al. (1982) reported the feeding practices of small ruminant farmers (Table 3). In the same locations, van Eys et al. (1984) reported the proportions of the feed offered to sheep and goats by feedstuff and season (Table 4).

Including leucaena in the diet is undoubtedly beneficial because of its high nutritive value (Table 2). The work of Wahyuni et al. (1981) on Ongole Grade bulls reported a daily gain of 0.54 kg from bulls fed 40% dried leucaena forage and 0.02 kg from those fed mainly natural grass. In a substitution trial, Siregar and Betta (1985) reported a daily gain of 0.25 kg from Ongole Grade × Brown Swiss growing bulls fed 50% leucaena meal and 50% soy cake meal, and 0.36 kg from those fed 100% soy cake meal. Musofie et al. (1983) reported that dried leucaena forage produced better daily gains compared with combinations with sugarcane tops in Bali heifers. Leucaena also gave better growth in Madura cattle (Soewardi and Basjuni 1980).

Leucaena, either fed fresh or as leaf meal, resulted in better daily gains in sheep and goats (Soedomo et al. 1983; Mathius et al. 1984; Semali and Mathius 1984; Rangkuti and Pulungan 1985; Sitorus 1987). Rangkuti and Djajanegara (1983) reported that leucaena leaf meal was not palatable to sheep, even when molasses was added to it. By comparison, leucaena leaf meal was palatable to goats, which

Table 3. Percentage of farmers feeding various forages to small ruminants at three locations in West Java.

Forage	Cirebon	Ciburuy	Garut
Elephant grass	0	1	1
Native grass	86	96	100
Corn tops	2	0	70
Legume straw	1	0	32
Rice straw	0	8	13
Cassava leaves	3	26	22
Sweet potato vines	0	1	3
Artocarpus heterophyllus leaves	0	5	10
Leucaena leucocephala leaves	1	5	1
Sesbania grandiflora leaves	20	0	0

Source: Sabrani et al. (1982).

Table 4. Composition (% of total feed, TF) of hand-fed small ruminant diets and frequency of feeding (% of flock receiving each feed, FF) at three locations in West Java.

		Garut		Ciburuy		Cirebon	
Feed	Season	TF	FF	TF	FF	TF	FF
Grasses[a]	Wet	65.2	95.2	91.4	100.0	61.8	72.4
	Dry	74.3	96.1	94.1	100.0	80.0	76.7
Herbs	Wet	3.1	12.0	3.7	18.2	11.3	11.2
	Dry	2.7	11.0	2.9	19.4	1.9	2.4
Crop by-products	Wet	20.8	66.8	2.7	21.1	12.8	10.5
	Dry	10.6	39.4	1.9	14.5	2.8	15.2
Shrubs and tree leaves	Wet	9.8	35.1	0.6	4.5	12.2	21.3
	Dry	11.5	38.7	1.8	4.2	15.0	18.2

Source: van Eys et al. (1984).

[a] Included sedges.

consumed as much as 311 g DM/head. Rachmadi and Reksohadiprodjo (1982) reported daily leucaena leaf meal consumptions of 260 and 217 g/head in sheep and goats, respectively, with no signs of negative effects.

No cases of toxicity have been reported in ruminants fed leucaena. Available data suggested that the optimal amount of leucaena in ruminant diets is 50%.

The situation is different in nonruminant livestock. Including leucaena in their diets produced negative effects. Rangkuti et al. (1984) reported that 30% leucaena leaf meal in the diet of young pigs arrested growth. Tangendjaja and Lowry (1985) reported that 10% leucaena leaf meal in the diet of broilers had no adverse effects, but growth was depressed at higher levels of leucaena leaf meal. Siregar et al. (1970) reported that leucaena leaf meal up to 10% did not affect the egg production of laying hens. Feeding leucaena ad libitum for a long duration reduced litter size considerably in rabbits as a result of embryo death and abortion (Gultom et al. 1987).

Calliandra at 60% produced a good daily gain in growing lambs (Datta et al. 1979). In broiler diets, Tangendjaja et al. (1987) reported that calliandra could only be included at up to 2.5%.

Limited data exists on the use of *Sesbania grandiflora* leaves as animal feed. Mathius et al. (1984) found that *Sesbania* leaves produced higher daily weight gain in lambs than did leucaena. The leaves of *Sesbania* are considered toxic to broilers. Tangendjaja (1988) stated that the leaves could only be included in broiler diets up to 2.5%. Up to 7.5% *Sesbania grandiflora* leaf did not affect egg production, feed intake, or feed conversion in laying hens (Isbandi et al. 1979).

Feed from gliricidia is relatively recent, and its use is receiving increasing research attention. Mathius et al. (1981) observed daily gains of 111 g for the wilted and 80 g for the fresh leaves in sheep receiving gliricidia leaves as the sole feed. This result was surprising and is much higher than those from the previous experiments where no concentrates were used. This encouraged further research on gliricidia as a supplement to the basal diets of sheep and goats (Mathius et al. 1984; Rangkuti et al. 1984; Rangkuti et al. 1985; Rangkuti and Pulungan 1985; Rangkuti and Martawidjaja 1988), Ongole Grade bulls (Rangkuti and Basya 1986), and lactating dairy cows (Wardhani et al. 1988). All these experiments showed positive results; the higher the intake on gliricidia leaves, the better the results. Rangkuti and Martawidjaja (1988) stated that to use the ingested nitrogen derived from gliricidia leaves more efficiently, readily available carbohydrates should be made available in the diet. Rangkuti et al. (1984) stated that, in general, the proportion of gliricidia in the diet would be 80% for sheep and 45% for goats. Feeding gliricidia intermittently (daily, every other day, or once every 3 days) at the same amount per unit time gave similar results in growing sheep and goats (Rangkuti et al. 1985).

The use of gliricidia leaves by farmers has been reported by Mawi et al. (1987) on sheep and goats in West Java, and by Sukardi (1988) in North Sumatera. Lowry et al. (1983) also reported the use of gliricidia without specifying the animals consuming it.

Gliricidia has a strong, unpleasant odour. Because of this odour, animals refuse to consume the fodder when it is first introduced. This can be overcome by wilting the leaves for 24 h at room temperature and training the animals step by step. This approach takes about 2 weeks (Mathius et al. 1981). A potential handicap is the fears among farmers that gliricidia can harm their animals (Mawi et al. 1987). This problem can be eliminated by more intensive extension work.

Constraints

Besides the negative effects to nonruminants, the limited number of extension officers with formal training in animal science is a major constraint in the government's efforts to popularize the use of shrubs and tree fodders. The use of farmers' groups in the campaign may be of great value. The influence and trust the groups have upon their members is a valuable means of intensifying their use of shrubs and tree fodders.

Another potential constraint is mineral deficiency. Many workers have reported both macro- and micro-mineral deficiencies in the soil, the forage, and the animals (Siregar et al. 1980; Siregar and Herawati 1981; Sutrisno et al. 1983; Prabowo et al. 1983; Prabowo et al. 1984). Available data suggest that mineral supplementation may double the growth rates of ruminants. Prabowo et al. (1983) reported that mineral supplementation yielded considerable improvement in sheep, mainly because of improved digestion of neutral detergent fibre.

Government policy

There were more than 28 million ruminants in Indonesia in 1987. More than 239 000 of these were distributed by the Indonesian government to farmers from 1984 to 1987, under the credit or sharing system. To meet the needs for roughage, the government combined the distribution of the animals with the distribution of forage seeds or other propagation materials through its nine institutes assigned to propagate and distribute stock animals and fodder plants throughout the country (Direktorat Bina Program Peternakan 1988).

The government places much emphasis on the success of such programs by providing funds and suitable facilities. Direktorat Bina Program Peternakan (1988) reported that in 1986/87 alone more than 2.8×10^6 Hawaiian-type leucaena seedlings were distributed throughout the country, involving more than 187 000 farmers' households. The government has also formulated programs to integrate livestock distribution with agroforestry development on critical lands, watershed, forest areas, etc.

The government pays special attention to the availability, distribution, and use of shrubs and tree fodders. The plantations in Timor and Flores (Piggin and Parera 1984) and in Madura (Siregar 1981) are examples of this. When *Heteropsylla* attacked leucaena in 1986, the government quickly imported Hawaiian beetles and distributed them. This was accompanied by a wide mass campaign, using all available media, on the wise use of pesticides, so that their application would not kill the domestic predators of the pest. The government considers that shrubs and tree fodders are a means to increase livestock production and farmers' income, as well as to improve the welfare of the entire population.

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Availability and use of shrubs and tree fodders in the Philippines

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Abstract *— Shrubs and tree fodders are unpopular among livestock farmers in the Philippines; this is because the country has underdeveloped dairy and beef industries and an import dependence on meat and milk. This implies that only a low livestock population can be supported by the available feed resources. This paper examines the role of ipil-ipil* (Leucaena leucocephala) *in livestock and poultry feeding in the past decade. The economic importance in relation to the multiple uses of the tree is discussed, together with the attention given to ipil-ipil by the government. The effects of* Heteropsylla cubana *infestation and the concept of crop diversity and integrated land management are presented. Characteristics and nutritive values of shrubs and tree fodders (with emphasis on* Gliricidia sepium*) are given and the role of this feed resource in future livestock development is discussed.*

Résumé *— Les paysans philippins qui élèvent du bétail n'aiment pas les arbres et les arbustes fourragers. Cela s'explique par le fait que le pays n'a qu'une industrie laitière et du boeuf de boucherie sous-développée et compte sur les importations de viande et de lait. Seul donc un petit cheptel peut être entretenu par les ressources disponibles en fourrage. L'auteur se penche sur le rôle joué par l'ipil-ipil* (Leucaena leucocephala) *dans l'alimentation du bétail et des volailles au cours de la dernière décennie. Il aborde l'importance économique de l'arbre en rapport avec les multiples usages de ce dernier et l'attention que le gouvernement lui porte. Il présente les effets de l'infestation à* Heteropsylla cubana *et le concept de la diversité culturale et de la gestion intégrée des terres. Enfin, il donne les caractéristiques et la valeur nutritive des arbustes et des arbres fourragers (s'attachant surtout à* Gliricidia sepium*) et discute du rôle de ce type de fourrage dans l'évolution de l'élevage.*

Resumen *— Los ganaderos de las Filipinas no usan comúnmente árboles y arbustos forrajeros, ya que el país ha desarrollado insuficientemente las industrias de la carne y de la leche, y depende de la importación para satisfacer la demanda de ambos productos. Esto implica que con los recursos alimenticios disponibles solamente puede tener una baja población ganadera. Este trabajo examina el papel del Intsia Bijuga* (Leucaena leucocephala) *como alimento avícola y ganadero de la década pasada. También, trata de la importancia económica respecto a la multiplicidad de usos de los árboles, y de la atención que dispensa el gobierno al Intsia Bijuga. Se consideran los efectos de la infectación con* Heteropsylla cubana *y se presenta el concepto de diversidad de los cultivos y explotación integrada de tierras. Se dan las características y los valores nutritivos de los arbustos y árboles forrajeros (con énfasis en el* Gliricidia sepium*) y también se trata el papel que desempeñará este recurso alimenticio en el desarrollo futuro de la ganadería.*

Introduction

Shrubs and trees have provided valuable fodder to domestic animals likely since the time of their domestication (Brewbaker 1985). This is particularly so in countries that have a progressive livestock industry coupled with problems of feed supply. The Philippines has strong swine and poultry production, which is well supported by a feed-milling industry. Beef and dairy production, however, lag far behind, with 50 and 99% of meat and milk requirements, respectively, being import-dependent. Whereas the beef and goat herds of the country are either grazed on open grasslands or tethered on marginal lands, dairy animals are supported by a very limited area of improved pastures, competing with other commodities for feed resources, and rely on crop residues during the dry season.

Tree fodders in the Philippines are largely contributed by ipil-ipil (*Leucaena leucocephala*). Except for this species, the concept of shrubs and tree fodders is new to livestock farmers, and the vast majority of researchers in the Philippines. Despite the widespread presence of leguminous and nonleguminous shrubs and trees in the country, their potential as fodders has not been explored; this also applies to most crop residues. The lack of popularity of shrubs and tree fodders in the Philippines is due to two main reasons: the problems encountered with ipil-ipil over the last two decades and the underdeveloped beef and dairy industry.

This paper reviews the Philippine livestock industry in relation to the feed resource situation, and recounts the contributions of ipil-ipil over the last 20 years. It also discusses promising substitutes for ipil-ipil and the challenges that face the livestock industry (BAI 1988).

Feed resources and the livestock industry

In the last 8 years, the Philippine human population increased from 48.1 to 58.7 million; the cattle population, however, decreased. The population of ducks and goats increased at a much higher rate (Table 1). As a result, the country depends on imports for its domestic meat and milk requirements (Table 2). In 1987 alone, the Philippines spent 157.7 × 10^6 USD on imported dairy products, which accounted for 99% of total dairy consumption. The underdeveloped dairy and beef industry translates into a lack of pressure to use and develop feed resources for ruminants.

Table 1. Human and livestock populations ($\times 10^6$) of the Philippines.

Population	1980	1984	1986	1988	Average annual growth rate, (%)
Human	48.1	53.4	56.0	58.7	2.5
Livestock					
Buffalo	2.87	3.02	2.98	2.93	0.3
Cattle	1.88	1.85	1.81	1.60	–1.9
Goats	1.67	2.36	2.18	2.06	3.1
Pigs	7.93	7.61	7.27	7.52	–0.6
Chickens	52.76	59.21	53.00	55.94	0.9
Ducks	4.72	5.76	5.21	6.27	3.9

Source: NEDA-NCSO (1987), BAI (1988).

Table 2. Livestock production, imports, and annual per-capita consumption of various commodities in the Philippines in 1987 and their annual growth rates (AGR, %) for the 1980s.

Commodity	Production		Imports		Per-capita consumption (kg)
	$\times 10^3$ t	AGR	$\times 10^3$ t	AGR	
Dairy, liquid milk equivalent[a]	11.5	0.5	1 360	5.8	27.2
Beef	90.5	3.2	4.4	25.2	1.3
Carabeef	45.3	3.3	—	—	0.6
Goat meat	34.9	10.0	—	—	0.4
Pork[b]	623.4	4.8	1.0	39.3	8.9
Chicken	164.0	1.7	—	—	3.1
Duck	4.3	–2.2	—	--	0.1

Source: BAI (1988).

[a] Under dairy, CIF (cost of insurance and freight) value is 157.7 × 10^6 USD (6.5% growth).

[b] Under pork, export value is 3 080 t (160.3% growth).

Table 3. Land use and production of major crops and their residues in the Philippines.

Land use/crop	Area ($\times 10^6$ ha)	Main product ($\times 10^6$ ha)	Residue ($\times 10^6$ ha)
Total land	30	—	—
Pasture land	1.1	—	—
Arable land	11.3	—	—
Rice	3.2	8.2	8.2
Corn	3.3	3.5	3.5
Sugarcane	0.4	3.2	0.6
Coconut	3.3	3.0	—[a]

Source: FAO (1985), NEDA-NCSO (1986).

[a] Assuming a carrying capacity of 0.25 animal units/ha, 0.8 × 10^6 animal units can be carried under coconuts (1 animal unit = 1 adult buffalo).

A common characteristic in animal holdings among Asian countries is the predominance of small-scale farmers. In the Philippines, 87% of cattle and 99% of carabaos (swamp buffaloes) are in the hands of small-scale farmers, who largely depend on marginal lands as their source of animal feed. Subtracting the number of cattle and carabaos held by backyard farmers from the animal population data presented in Table 1, there is a balance of about 240 000 large ruminants kept in commercial farms and ranches. In relation to the total pasture land of 1.1 × 10^6 ha (Table 3), this provides a low stocking rate of 0.21 head/ha. This stocking rate could be at least tripled by introducing leguminous trees. For the small-scale farmer, rice, corn, and sugarcane alone generate 12 × 10^6 t/year of crop residues (Table 3); these are also currently neglected. Trung (1987) estimated that 4.8 million more cattle and carabaos could be raised on fodder under coconuts and residues from the major crops.

In summary, the Philippines has considerable untapped feed resources. The current ruminant population could be more than doubled by improving the carrying capacity of permanent pastures, fully using crops residues, and introducing shrubs and fodder trees in marginal lands and pasturelands. The most recent policy guidelines from the Department of Agriculture on livestock, with an emphasis on dairy development (BAI 1988), suggest that forages from shrubs and trees will play an important role in supporting local livestock production in the future.

Ipil-ipil: the wonder tree

Among Asian countries, the Philippines and Indonesia have made the most use of ipil-ipil (*Leucaena leucocephala*) (Napompeth et al. 1987). Until the devastating infestation in the mid-1980s of *Heteropsylla cubana*, ipil-ipil was found throughout the Philippines: in the forest for reforestation, in marginal lands for producing animal feed, and in the cities for shade. Because it is a fast-growing multipurpose tree, it has been considered as a miracle or wonder tree. Among its many uses, its value as feed is perhaps most widespread, producing leaf meal and fodder for ruminants.

Origin, habitat, and varieties

Although ipil-ipil is an old crop in the country, its large-scale production was triggered in 1969 by the improved varieties of the giant K lines from the collection of Dr James L. Brewbaker of the University of Hawaii (Mendoza 1984). Under Philippine conditions, ipil-ipil grows best at an elevation of up to 460 m above sea level. It grows on almost any type of soil with annual rainfall ranging from 400 to 800 mm. However, it does not tolerate acidic conditions (pH 5). Ipil-ipil can withstand prolonged drought, but not waterlogged soils. From among 125 accessions, including 70 foreign introductions, many breeding and agronomic trials have been conducted to determine suitable varieties and management practices (Mendoza 1984). There are two recommended types for the Philippines: the Salvador type (also known as Hawaiian Giants K8, K28, and K67) and the Peruvian type. The Salvador type is tall with large leaves, pods, and seeds, and thick branchless trunks, more suitable for timber, wood products, and industrial fuel than for fodder. The Peruvian type is also tall but has extensive branching, even low down on the trunk. These plants have small trunks, but produce high-quality foliage on their branches, with large leaflets and pods.

General uses and economic importance

In the Philippines, there are six main uses of ipil-ipil:

- as a source of wood,
- for reforestation and erosion control,
- as greenery and for shade,
- as fertilizer,
- in agroforestry, and
- to produce animal feed.

Wood produced from ipil-ipil makes good fuel and charcoal, roundwood (poles and posts), banana props, lumber, veneer and plywood, parquet flooring, particleboard, fiberboard, pulp and paper, and dissolving pulp. Ipil-ipil is one of the fastest growing hardwood species in the Philippines with annual growths ranging from 24 to 312 m/ha or 13 to 150 "bone dry" t/ha, depending upon site quality and strain (PCARRD 1980a).

Ipil-ipil is a good forerunner in reforestation. It can be planted successfully in grassland areas, preparing the land for other, more favoured species. Well-established ipil-ipil shade out undergrowth, eliminating combustible materials under them. Ipil-ipil also serves as a windbreak in typhoon-prone areas like Batanes, the Bicol region, and Quezon.

Being a leguminous plant, ipil-ipil is an excellent source of organic fertilizer. It can either be intercropped or grown immediately after harvest. This has been successful with coconut, coffee, tea, fruit trees, banana, corn, sorghum, rice, and other agricultural crops (PCARRD 1980a). Leucaena foliage as green manure provides organic matter that increases aeration, water retention, insulation, and cation exchange capacity. The leaves of ipil-ipil contain about 0.6% nitrogen (N) in terms of green weight or 4.3% in terms of dry weight.

The progressive backyard beef production in Batangas province is attributed to the use of ipil-ipil, known in the area as "lepili." Small-scale farmers in Batangas pound ipil-ipil foliage and then mix it with water, rice bran, and salt. The liquid mixture is then drenched to individual cattle. This method of feeding is known locally as "supak," and is also practiced in other parts of the country.

The most significant contribution of ipil-ipil to small-scale farmers is in the production of leaf meal. This has become a cottage industry for many families, particularly those in Central and Western Visayas and Northern Luzon. Farmers simply cut and gather ipil-ipil branches. The leaves are dried under the sun along roadsides and front yards and then threshed by families for extra income. Some of the feed mills in the Philippines have buying stations for dried ipil-ipil leaves in the barrios (villages). The price depends on the colour, dryness, and purity of the product.

It is estimated that with 5% ipil-ipil leaf meal in swine and poultry feeds, the yearly requirement for this leaf meal among commercial feed millers is 50 000 t. In 1980, local leaf meal production was 20 000 t (PCARRD 1980b). Limited amounts of ipil-ipil pellets have also been exported to Japan. Export, however, is regulated to give priority to local consumption.

Financing ipil-ipil production

The Development Bank of the Philippines (DBP) launched a smallholder tree-farming project in 1978 with *Albizia falcataria* and *Leucaena leucocephala* as the principal species (the former was introduced in 1972). This project aimed at providing adequate and timely credit assistance to small-scale farmers with landholdings not exceeding 50 ha, either owned or leased, and intended for the propagation of fast-growing trees, especially on poor or marginal areas. After 3 years, the project benefited 237 farmers cultivating an area of over 3 000 ha, with the total amount of money loaned at 6.5×10^6 PHP (Diaz 1984) (in July 1989, 19 Philippine pesos [PHP] = 1 United States dollar [USD]). The maximum loan given to a farmer is 2 500 PHP/ha with an estimated gross income of 5 000 to 9 000 PHP over a period of 4 years for leaf meal and charcoal production, respectively. Diaz (1984) further pointed out that for every hectare of ipil-ipil plantation, the employment generated is equivalent to 4 500 PHP, which, for the 3 000 ha in this project, generated over 13.5×10^6 PHP.

Research and development on fodder production

Many research projects on ipil-ipil production and use have been undertaken by different institutions in the Philippines over the past 15 years. The main findings and recommendations are presented here.

Ipil-ipil cultivation

Mendoza (1984) drew the following six conclusions on management and yield following a decade of research at the University of the Philippines at Los Baños:

- Use only seeds with known purity and ability to germinate. Mixed or uneven stands tend to depress yields and make harvesting difficult.
- Plant in well-drained, near-neutral soil. Otherwise, provisions should be made to approximate these conditions.
- For high population density (250 000/ha), the optimum cutting height is 15 cm and the best cutting frequency is 60 days.
- For spaced plantings, optimum density per hectare is 10 000 to 20 000, with at most 1 m cutting height and 60 days cutting interval.
- The wood types (K8, K28, and K67) could also be managed for forage, provided they are planted at high densities and clipped more frequently (45–60 days).
- Annual dry matter yields ranging from 10 to 25 t/ha are possible depending on the combination of inputs and management techniques employed.

Ipil-ipil in agroforestry

Although ipil-ipil has been widely intercropped by Filipino farmers with a number of agronomic and horticultural crops, little attention has been paid to the fodder generated in these systems. The tree is simply treated as a source of green manure, shade, and nitrogen for the main crops, e.g., coffee, tea, cacao, rubber, young coconut, pepper, vanilla, citrus, pineapple, cassava, sweet potato, peanuts, papaya (PCARRD 1980a; Nguyen 1987).

Mabbayad et al. (1984) recommended the use of single hedgerows (2 m apart) intercropped with corn. This method eliminated inorganic fertilizer without affecting the yield of corn grain. Yields of 35.6 t/ha fresh forage were obtained after 16 months and five prunings with two corn intercrops. Nguyen (1987) demonstrated the workability of intensive agroforestry systems on land with a 15% slope in which ipil-ipil was intercropped simultaneously with papaya, pineapple, sweet potato (followed by peanuts), and cassava in contour furrows. This intensive system improved soil characteristics (except pH), completely controlled surface runoff and soil erosion, and increased productivity of the crops. This system generated 20 t/ha of green forage in 18 months. Kang et al. (1984) likewise recommended alley cropping as a stable alternative to shifting cultivation using ipil-ipil and other tree species intercropped with maize, cassava, and cowpea. In this system, 15–20 t/ha of fresh prunings (5.0–6.5 t/ha dry matter) was produced with five prunings per year.

Ipil-ipil was used in these research projects primarily to maintain soil fertility for the food crops. It should, nevertheless, be pointed out that the forage generated in those systems, in addition to the crop residues available at harvest time, pose a very good opportunity for enhanced livestock production, particularly in upland areas.

Ipil-ipil fodder for ruminant production

In small farms, ipil-ipil for cattle feeding is normally grown in hedgerows to avoid using land valued primarily for crop production. In the hilly areas of Batangas province, ipil-ipil is intercropped with "atis" (*Anona squamosa*) and used extensively as cattle feed. Farmers observed that "atis" plants grown with ipil-ipil produced bigger fruits. A case study (Moog 1984) in Batangas involving a farmer with 2 ha of ipil-ipil planted in rows 3 m apart and anona trees between the rows showed that 20 growing cattle could be supported. Harvesting every 40–60 days, the farmer shared the extra feed with his neighbours and prevented the anona plants from being shaded. Moog (1984) observed that cattle fatteners in Batangas fed 350-kg steers at a daily rate of 5–20 kg fresh leucaena/head and obtained an average daily live weight gain of 0.5 kg, which could be increased to 0.8 kg with rice bran and other concentrate supplements. Without ipil-ipil and other supplements, cattle would gain about 0.3 kg daily.

The introduction of ipil-ipil to cogon (*Imperata cylindrica*) grassland to increase stocking rate has been studied (Moog et al. 1980). In a 315-day grazing trial involving swamp buffaloes, stocking rate doubled from 0.75 to 1.5 animal units/ha with the introduction of ipil-ipil (1 animal unit = 1 adult buffalo). Average daily gain and total weight gain likewise increased from 0.22 to 0.35 kg/ha and 51.1 to 167.9 kg/ha, respectively. The authors did not recommend further increase in stocking rate to 2 animal units/ha because of possible pasture depletion from overgrazing. One hectare of Guinea grass–ipil-ipil mixed pasture can support two and five head of grazing cattle during the dry and rainy seasons, respectively. An average daily gain of 0.5 kg/head could be expected, which is equivalent to 440 kg live weight/ha per year.

The use of ipil-ipil as a supplement to rice straw has been studied extensively in the Philippines using growing goats (Arinto 1979; Rasjid and Perez 1980), growing dairy heifers (Trung et al. 1984), and lactating cows (Trung et al. 1986). Likewise, ipil-ipil has been used to supplement protein-deficient but energy-rich corn silage for dairy cattle (Tables 4 and 5) (Trung et al. 1985; Escaño and Trung 1986). For cows in early and mid-lactation fed complete diets containing 60% dry matter from corn silage, replacing the concentrates (40% of diet dry matter) with ipil-ipil (20–30% of diet dry matter) did not alter milk production and feed efficiency. With rice straw levels ranging from 35 to 50% of total diet, ipil-ipil was included fresh, dry, or as leaf meal at 40–50% to replace conventional concentrate mixtures. In growing–fattening trials, when ipil-ipil partially replaced the concentrate (up to 72%), no significant changes in average daily gain (0.50–0.58 kg) were obtained. Feed efficiency was not as good in diets containing ipil-ipil as in those with concentrates (15.6 vs 11.9 kg/kg); however, the lower costs of the former offset the relative disadvantage in efficiency (4.6 vs 10.3 PHP/kg weight gain, respectively).

Table 4. Ipil-ipil as a supplement to rice straw for growing animals.

Diet[a]	Dry matter intake ($g/kg^{0.75}$)	Average daily gain (g)	Feed/gain
	Philippine goats, 84 days[b]		
30% RS + 70% I	64.8a	35.7b	12.6b
30% RS + 50% I + 20% RB	71.8a	68.6a	7.7a
30% RS + 50% I + 20% M	70.4a	50.0ab	10.5b
	Crossbred replacement dairy heifers, 180 days[c]		
35% RS + 65% C	95.3b	500a	11.9a
35% RS + 45% I + 20% C	131.3a	580a	15.6a

Note: Mean values in the same column for the same animal followed by the same letters are not significantly different ($P < 0.05$).

[a] RS, rice straw; I, ipil-ipil; RB, rice bran; M, molasses; C, coconut cake.

[b] Source: Rasjid and Perez (1980).

[c] Source: Trung et al. (1984).

Table 5. Ipil-ipil as a supplement to rice straw or corn silage for crossbred lactating cows.

Diet[a]	Dry matter intake (kg)	Daily milk yield (kg)	Feed/milk
	Whole first lactation[b]		
35% RS + 65% C	9.45a	1 822a	1.09a
35% RS + 45% I + 20% C	12.65a	2 083a	1.53a
	First 120 days of lactation[c]		
60% CS + 40% C	8.79a	7.37a	1.21a
60% CS + 20% I + 20% C	9.68a	7.60a	1.36a
	96-day midlactation[d]		
60% CS + 40% C	10.62a	10.00a	1.06a
60% CS + 30% I + 10% C	10.80a	9.90a	1.09a

Note: Mean values in the same colomn for the same lactation stage followed by the same letter are not significantly different ($P < 0.05$).

[a] C, coconut cake; I, ipil-ipil; RS, rice straw.

[b] Source: Trung et al. (1986).

[c] Source: Trung et al. (1985).

[d] Source: Escaño and Trung (1986).

Likewise, with a complete lactation length involving first-calved dairy heifers, Trung et al. (1986) did not find significant differences in milk yield, milk composition, milk quality, or prepartum and postpartum reproductive performance between the cows fed ipil-ipil diets and control diets. Income above feed cost was higher when ipil-ipil replaced 72% of the concentrate mixture.

Toxicity of ipil-ipil because of mimosine or its metabolized form, DHP

(3,4-dihydroxypyridone), has not been encountered in the Philippines. For swine and poultry, this is due to the strict 5% upper limit for ipil-ipil leaf meal observed by commercial feed millers (PCARRD 1980b). Long-term feeding trials with cattle did not result in any ill effects on productive and reproductive performance (Tables 4 and 5). Likewise, Arinto (1979) fed Philippine goats with rations containing 0 to 75% ipil-ipil and reported better growth rates for goats with higher ipil-ipil levels without adverse effects on various reproductive parameters.

Psyllid infestation

Psyllid infestation, which is caused by *Heteropsylla cubana* or jumping plant lice, was observed simultaneously in the provinces of Cebu, Laguna, Batangas, and Rizal in February 1985. By September, the pest was present in huge numbers throughout the country. In 1985, the majority of ipil-ipil trees in the Philippines were almost completely defoliated.

Three national meetings among administrators, researchers, and extension workers were held in 1986-87 to assess the extent of the damage and to identify preventive and control measures. Pollisco (1987) synthesized the meetings and concluded that *H. cubana* infestation in the Philippines is nationwide. The total area of ipil-ipil infested by the pest nationwide is not available, but estimates of over 3 000 ha in Northern Luzon, 450 ha in Visayas, and 2 600 ha in Mindanao have been suggested. Because of even rainfall distribution, the degree of damage in Mindanao was not serious. No records have been made available for the provinces of Cebu and Southern Tagalog, where the infestation has been considered the most severe.

The National Electrification Administration (NEA) has 22 tree plantation projects nationwide. Massive attacks by ipil-ipil psyllid on NEA plantations were reported during the first quarter of 1986. In the second quarter of the same year, 18 sites were confirmed to be infested, ranging from mild to almost 100% infestation. Less affected were those areas belonging to "type C" climate, (rain sufficiently distributed throughout the year, with at most 4.5 dry months). Immediate actions of NEA included cutting down the trees, chemical spraying, and introducing alternative fast-growing species: *Acacia mangium*, *Acacia auriculaeformia*, *Gmelina* spp., *Eucalyptus* spp., *Gliricidia sepium*, and alibangbang or *Bauhinia* spp. (Pollisco 1987).

Ipil-ipil infestation has been claimed to affect the environment directly through microclimatic modification. It is a hindrance to reforestation and afforestation activities, as well as a problem to watershed management. Indirectly, it can increase the depletion of remaining forests as farmers substitute ipil-ipil with other species. Stabilized sloping uplands may likewise be seriously affected, thus further aggravating soil slippage and erosion in these uplands, which can cause siltation in the lowlands and water reservoirs. In areas where ipil-ipil is a major species for reforestation, the absence of leaves increases penetration of solar radiation, thereby heating the soil. The increased soil temperature causes higher mortality of plants, abnormal microbial activity, slower evapotranspiration, and reduced air humidity (De Guzman 1987a). The fallow period required in shifting cultivation to regenerate nutrients may become longer. In extreme situations, upland areas may become unproductive and end up as grassland. Similarly, pastures may be overgrazed because of the over-dependence of the livestock industry on ipil-ipil.

The area most dramatically affected by the infestation is the livestock sector. The following accounts indicate the severity of the problem (De Guzman 1987b):

- About 2 000 ha of ipil-ipil, managed by the Manila Seedling Bank Foundation in Novaliches, Rizal, has produced no leaf meal since August 1985. A normal annual income of 8×10^6 PHP is expected from leaf meal production.
- Bureau of Animal Industry reports indicate that in Barrio Malimatoc, Mabini, Batangas, where small farmers use ipil-ipil as the major feed for cattle, psyllid infestation caused a drastic feed shortage for all 31 farmers surveyed. Lower quality feed substitutes such as banana leaves and trunks, corn stover, and coconut fronds were used. Consequently, 23 farmers claimed that their animals lost weight, 9 said their cattle became sick, 4 reported death of animals, and 26 reported a loss of profits. The number of animals owned by these farmers dropped from 116 to 53.
- In Cebu, three associations of ipil-ipil farmers, with a total of 770 members, each used to harvest 6–8 t/month of dried leucaena leaves. None has been harvested since the psyllid outbreak. One pelleting plant in Cebu reduced its work force from 50 to 4, and several plants in the same area stopped operations temporarily. Transactions in the livestock market eventually decreased.

Efforts have been made to alleviate the situation: i.e., chemical controls, biological controls, breeding, and introducing resistant species and accessories. Whereas the first three measures are still subject to research, the last measure has not contributed much because of the cost and lack of appropriate seeds. In Los Baños conditions, *Leucaena macrophylla*, Hawaiian hybrid (K67), and *Leucaena collinsii* have field tolerance (De Guzman 1987b). Studies are being conducted worldwide to determine the resistance of ipil-ipil and other legumes to the psyllid (e.g., Sorensson and Brewbaker 1987).

Substitutes for ipil-ipil

The Philippine experience with psyllid infestation demonstrates the dangers of depending on one leguminous tree, such as ipil-ipil. The concept of crop diversity and integrated land management for subsistence farmers is now seriously recognized by researchers and policymakers. Many shrub and tree species have been tried as replacements for ipil-ipil in contour hedges or plantations (Tables 6 and 7).

The tree that appears to be attracting the most attention is *Gliricidia sepium*. Known locally as "kakawate" or "madre de cacao," gliricidia is found in the Philippines from 6° to 19° N and at altitudes from sea level to 900 m in the four climatic types (Perino 1979). Gliricidia grows in most adverse sites, including areas where ipil-ipil does not thrive. It is a drought-resistant species that sheds its leaves during the dry season (November to April), when green feed is badly needed. This drawback is overcome by lopping the tree 2 or 3 months before the onset of the dry

Table 6. Promising shrub and tree species as substitutes for ipil-ipil in the Philippines.

Species	Comments[a]
Acacia villosa	• Rapid growth and good biomass production; tolerant to drought and infertility. • Prolific seeding, may become an aggressive weed; questionable fodder value. • Being recommended in Mindanao.
Albizia falcalaria	• Introduced to small tree farmers ahead of ipil-ipil (1972 vs 1978). • Experience elsewhere indicates tolerance to acid soils and good for fuel and other wood uses.
Bauhinia menandra	• Being tested at FSSRI, UPLB.
Cajanus cajan	• Being tested at IRRI. • Multipurpose perennial shrub.
Cassia spectabilis	• Grows well along roadsides in Mindanao, is being tried successfully as ipil-ipil replacement in Cagayan de Oro.
Desmanthus virgatus	• Being tested at IAS, UPLB, and IRRI. • Research elsewhere indicates drought but not acid tolerant; aggressive; coppicing and reseeding well.
Erythrina sp.	• Being tested at FSSRI and IAS. • Good hedgerow and shade species. • Established by stem cuttings.
Gliricidia sepium	• In Cagayan de Oro, showing excellent promise as a green manure crop in alley cropping. • Widely used as shade for coffee and cacao; wood used for fencing, orchid growing. • Considered by farmers as unpalatable to livestock. • Although best propagated by seeds, stem cuttings are possible.
Hibiscus tileaceus	• Being tested at IAS. • For alley cropping (elsewhere).
Moringa oleifera	• Being tested at IAS and FSSRI. • Farmers planting as replacement for ipil-ipil; used as vegetable. • Findings indicate drought tolerance, low biomass production, and poor coppicing; grown from seeds and stem cuttings.
Pithecellobium dulce	• Being tested at IAS and FSSRI. • Findings indicate wide uses and adaptability.
Samanea saman	• Widely grown throughout the country and used as shade and craftwood/timber. • Susceptible to *H. sesbania* attack.

(continued)

Table 6. Concluded.

Species	Comments[a]
Sesbania grandiflora	• Used as vegetable and wood for fuel and fencing. • Findings show good intercrop with cassava, maize, peanuts, and soybeans; slow foliage regeneration.
Sesbania rostrata	• Being tested at DTRI and IRRI. • Very fast-growing and excellent N-fixer, but photosensitive.
Tamarindus indicus	• Being tested at FSSRI.
Trema orientalis	• Used as shade for commercial crops in agrosilviculture. • Being tested at IAS.

[a] FSSRI, Farming Systems and Soil Resources Institute; UPLB, University of the Philippines at Los Baños; IRRI, International Rice Research Institute; IAS, Institute of Animal Science; DTRI, Dairy Training and Research Institute.

Table 7. Nutritive value of fodders of some shrubs and trees (% dry matter basis).

Species	DMD	CP	CF	Ca	P
Albizia falcalaria	—	21.2	37.0	—	—
Cajanus cajan	—	17.3	28.1	—	—
Leaf	53	15.8	29.2	—	0.22
Small stem	42	10.5	48.7	—	0.25
Meal	—	14.8	28.9	—	—
Desmanthus virgatus					
Leaf	53	14.6	19.5	—	0.19
Stem	32	7.0	50.5	—	0.17
Gliricidia sepium					
Leaf	55–68	16–28	21	—	0.13
Leucaena leucocephala	51–71	22	14	2.7	0.17
Leaf	69	16	18.3	—	0.17
Stem	26	4.4	57.7	—	0.22
Samanea saman	—	24	48	—	—
Sesbania grandiflora	—	30–35	5–7	2.3	0.33
Tamarindus indicus	—	14–23	6–19	—	—

Note: DMD, dry matter digestibility; CP, crude protein, CF, crude fibre.
Source: Brewbaker (1985).

season. New shoots would grow and succulent feeds would be produced during the dry season. Easily propagated by seeds and cuttings, gliricidia replaces ipil-ipil very well in alley cropping, as a shade tree, and for green manure, fodder, and fuelwood. It coppices vigorously and tolerates regular lopping. In addition, zero cutting for 4 to 6 months also allows regrowth of branches large enough to be used as fuelwood in addition to the leaves.

Based on a 60-day cutting interval, Calub (1988) estimated that 200 trees in a hedgerow or a living fence of gliricidia planted 1 m apart could provide 25% of the daily feed required by a 300 kg cattle on a year-round basis. This is based on an annual dry matter yield per tree of 0.47 kg/cutting in the Bali accession. Calub (1988) cited an experiment from Sri Lanka suggesting that gliricidia planted 0.45 m apart yielded 4 kg edible fresh leaves per tree per year; hence, 400 m fenceline

Table 8. Edible herbage dry matter yield of fodder trees at Los Baños, Philippines.

			1987				
	1985		Dry season (Jan–May)		1 year		1988
Species	g/cutting per tree	g/tree per year	g/cutting per tree	g/tree	g/cutting per tree	g/tree per year	One harvest
Leucaena leucocephala[a]	361	722 (2)	274	274 (1)	274	547 (2)	—
Trema orientalis	143	143 (1)	921	1 842 (2)	504	2016 (4)	99
Pithecellobium dulce	258	258 (1)	434	867 (2)	224	1 342 (6)	51
Moringa oleifera	259	259 (1)	238	475 (2)	128	765 (6)	167
Gliricidia sepium							
Local	196	196 (1)	717	1 434 (2)	330	1 980 (6)	68
Bali[b]	—	—	898	1 796 (2)	364	2 181 (6)	93
Desmanthus virgatus[b]	—	—	272	815 (3)	160	960 (6)	43
Hibiscus tileaceus[c]	—	—	441	441 (1)	187	747 (4)	64
Erythrina sp.[b]	—	—	867	867 (1)	243	1 213 (5)	66
Sesbania grandiflora[b]	—	—	883	1 765 (2)	434	1 971 (6)	42
Albizia lebeckoides[c]	—	—	192	192 (1)	185	371 (2)	—

Note: No cutting was done in 1986. Values in parentheses indicate the number of harvests.

Source: Calub (1988).

[a] *Heteropsylla* infestation allowed two harvests in 1985 and two harvests in 1987.

[b] Included in the 1986 test, but harvesting was done in 1987.

[c] Included in the 1987 test.

would support 25% of the feed requirement of a milking cow. For gliricidia plantations, Brewbaker and Glover (1988) reported dry leaf production of 12–36 t/year from 10 000 trees/ha with cutting intervals of 1–3 months. An ongoing fodder tree project indicates good potentials of gliricidia, catuiray (*S. grandiflora*), and *Trema orientalis* among others as possible substitutes for ipil-ipil as sources of green fodders, particularly during the dry season (Table 8).

Few feeding trials are being conducted with shrubs and tree fodders. At the Dairy Training and Research Institute, supplementary quantities for gliricidia, *Sesbania*, and *Boehmeria nivea* (ramie) to rice straw and grass are being determined using goats and cattle. As supplements, these feeds do not pose any palatability problem.

Fodder trees are being incorporated into goat production at the Mindanao Baptist Rural Life Centre (MBRLC) (Watson 1988). The dairy system uses 0.25 ha to support six does and their kids plus one buck. The plot is divided as follows: one-half planted to energy feeds such as sweet potato and cassava; one-quarter planted to protein supplements such as *Sesbania sesban* and *Calliandra callothyrsus*; one-eighth planted to napier grass; and the remaining one-eighth is contour lines of high-quality legumes like *Desmodium gyroides*, *Desmodium ransonie*, *Flemingia congesta*, and *Leucaena diversifolia*. Boundaries are planted with gliricidia. This system has been operating now for 2 years and is nearly sufficient in feed requirements. The MBRLC trial is an excellent example of how intensive livestock production can work in a self-reliant system that makes full use of land resources, with fodder trees playing an important role. Better or more suitable systems could be designed not only for Mindanao but also for other parts of the country.

The Government is giving a high priority to livestock development, and it is envisaged that the current ruminant population can be doubled or more. Considering the pressure on land use to support the ever-expanding human population, intensive livestock production appears to be the only solution. Maximum use of locally available feed resources is therefore essential. This would mean full use of crop residues and forages from marginal land and strategic supplementation with mainly high-quality leguminous fodders from shrubs and trees that can be conveniently planted on marginal lands, along fences, and along sidewalks. Shrubs and tree fodders would therefore be considered as a catalyst for increased ruminant production. Without this important feed ingredient, the full use of poor-quality feedstuffs, which are being neglected at the moment, is unlikely to be realized.

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Availability and use of shrubs and tree fodders in China

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Abstract — *This paper reviews information on the availability and use of shrubs and tree fodders in China. It is estimated that there are more than 400 species of shrubs and fodder trees in China, which could produce over 500 × 10^6 t of fodders for animals. Their use is currently underestimated. Data are given on the nutrient contents of some tree leaves and on the use of feeds from* Pinus *spp. for egg production and* Robinia pseudoacacia *by pigs. Up to 10%* Leucaena leucocephala *leaf meal in the diet has been found to be beneficial to pigs. The importance of developing shrubs and trees for fodder to keep pace with an anticipated expansion in animal production is emphasized.*

Résumé — *L'auteur passe en revue l'information sur la disponibilité et l'utilisation, en Chine, des arbustes et des arbres fourragers, dont il y aurait plus de 400 espèces, capables de produire plus de 500 × 10^6 t de fourrage. Leur utilisation est actuellement sous-estimée. Il avance des chiffres sur les nutrients contenus dans certaines feuilles d'arbre et sur l'emploi de* Pinus *spp. dans l'alimentation des volailles pour accroître leur production d'oeufs et de* Robinia pseudoacacia *dans l'alimentation des porcs. Les feuilles de* Leucaena leucocephala, *données sous forme de farine formant un maximum de 10 % de leur ration, seront bénéfiques aux porcs. L'auteur insiste sur l'importance de la mise en valeur des arbustes et des arbres fourragers en prévision de l'expansion prévue de la production animale.*

Resumen — *Este trabajo analiza la información relativa a la disponibilidad y uso de arbustos y rboles forrajeros en China, donde se calcula que hay más de 400 especies de arbustos y árboles forrajeros que podrían producir más de 500 × 10^6 t de forraje para animales. Se desestima su uso en la actualidad. Se brinda información respecto al contenido de sustancias nutritivas de algunas hojas de árboles, al uso de forraje obtenido de* Pinus *spp. para la producción de huevos y a la utilización de* Robinia pseudoacacia *como forraje para porcinos. Se descubrió que hasta un 10% de harina de hoja de* Leucaena leucocephala *en la ración alimenticia de los cerdos resulta provechosa para ellos. Se pone de relieve la importancia de desarrollar arbustos y árboles destinados al forraje para avanzar al ritmo de la expansión prevista en la producción animal.*

Introduction

Shrubs and tree fodders are traditional, important feed resources in China, especially for cattle, sheep, and goats. Species used are very diverse and are found in various climates. More than 400 species of trees and shrubs are cultivated, widely distributed, used by farm animals (Feng 1985), and of economic importance (Cai 1986). More than 500 × 10^6 t of tree fodder could be produced annually (Feng 1985; Wang 1985; Liu 1987). If only one-fifth of this is used as animal feed, the amount would be three times the total grain feed that is now used in livestock feeding. This great potential has attracted much attention because of the serious shortage of feed and arable land in China. Unfortunately, research on the availability and use of tree fodder is limited. Nevertheless, this paper reviews the results available in China.

Resources and evaluation

In terms of morphology and origin, tree fodders can be divided into three groups: needle leaves, broad leaves, and shrubs. The first two comprise forests; the third is an important component of the grasslands of China. A lot of research is necessary to get a clear idea about the amount of resources and their nutritional value. Some of the more important tree fodders are discussed here.

Pine needles

Pine needles are one of the main needle leaf fodders in China. They are produced industrially and used widely as animal feed, especially for pigs and poultry. There are more than 30 varieties of pine in China and at least 300 × 10^3 t of pine needle leaf meal could be produced annually (Huang 1985).

Crude protein varies among different varieties, as does the ether extract (Table 1). Ether extract contents of pine needle leaf are high. Values for total digestible nutrients have not been reported. In pig and poultry diets, pine needle leaf meal is used to supplement vitamins and trace minerals. Limited analysis indicates that pine needle leaf meal contains more than 120 ppm carotene, 522 ppm vitamin C, 3.8 ppm vitamin B, 17.2 ppm vitamin B_2, and 3.6 ppm selenium (Liu 1985; Li 1986). Soil analysis has shown that a large part of China is deficient in selenium. Pine needle leaf meal is rich in selenium and a good source of vitamins.

Zhao and Liu (1985) used pine needle leaf meal (*Pinus massoniana*) to replace 5% of corn in the diets of growing-finishing pigs. The daily weight gain was 572.3 g for the experimental group and 566.7 g for the control group. Li and Yu (1982) fed pine needle leaf meal to laying hens; diets contained 0, 3, 5, and 7% leaf meal. The best egg production rate was observed with the 5% leaf meal diet. In a second experiment, Li and Yu (1982) examined the effects of vitamins in pine

Table 1. Nutritive value of pine needle leaf meal (% dry matter basis).

Species	CP	EE	CF	NFE	Ash	Source
Pinus massoniana	8.5	7.7	29.2	51.3	3.3	Li (1986)
	25.5	5.0	22.5	42.4	4.6	Zhao and Liu (1985)
Pinus densiflora + *P. thunbengii*	9.7	12.0	29.4	45.1	3.7	Liu (1985)
Pinus densata	13.5	6.5	18.0	55.1	6.9	Liu (1985)
Pinus spp.	7.8	11.4	34.4	43.1	3.3	Liu (1987)

Note: CP, crude protein; EE, ether extract; CF, crude fibre; NFE, nitrogen-free extract.

Table 2. Effect of pine needle leaf meal on egg production.

	Treatment		
	I	II	III
Diet			
Base diet (%)	94	94	100
Pine needle leaf meal (%)	6	6	—
Vitamin complex (g/50 kg)	—	2.5	5
Egg production rate (%)			
One month before experiment	42.5	42.9	42.6
End of experiment (66 days)	54.5	63.2	60.7
20 days after experiment	49.8	53.9	51.8

Source: Li and Yu (1982).

needle leaf meal. The pine needle leaf meal could replace 50% of vitamin complex in laying hen diets (Table 2). Some reports also indicated the colour of the egg yolk improves if pine needle leaf meal is included in the diet (e.g., Liu 1987).

Broad-leaf fodders

A lot of broad-leaf tree leaves can be used by farm animals. Important trees include poplar (*Populus*), willow (*Salix*), elm (*Ulmus*), locust (*Robinia pseudoacacia*), and some fruit trees. The leaves are generally 5% of total tree's weight (Liu 1987). Total edible broad leaves useful for animals are estimated at 300 × 10^6 t (Liu 1987; Huang 1985). Broad leaves are all rich in nutrients, especially crude protein and vitamins (Table 3).

Li and Zhou (1987) fed poplar leaf meal (*Populus acladesca*) to 35-week-old broilers. The base diets contained 16.4% crude protein, 11.77 kJ/kg metabolizable energy (ME), and a vitamin complex. The results indicated that increasing levels of leaf meal reduced egg production after 60 days (Table 4). Also, the egg yolk colour in groups I to III was much better than that in group IV, and 40% of the vitamin complex could be saved if the diet contained 7% poplar leaf meal.

The crude protein content of locust tree leaf meal is high, but varies with collecting season. The digestible energy of locust tree leaf meal for pigs was measured at the Sichuan Provincial Research Institute of Animal Husbandry and

Table 3. Nutrient content of tree leaves (% dry matter basis).

Species	CP	EE	CF	NFE	Ash	DE (kJ/kg)
Populus acladesca[a]	13.4	4.5	16.3	55.8	10.0	—
Robinia pseudoacacia[b]						
Spring	27.7	3.6	12.8	38.1	7.8	—
Summer	24.7	3.6	14.8	49.1	7.9	—
Autumn	19.3	5.0	19.4	48.9	5.5	—
Robinia pseudoacacia[c]						
Pinchangn county	20.7					5.7
Bazong county	19.4	5.6	19.2	48.1	7.5	4.5

Note: CP, crude protein; EE, ether extract; CF, crude fibre; NFE, nitrogen-free extract; DE, digestible energy (dry matter basis).

[a] Source: Li and Zhou (1987).

[b] Source: Liu (1987).

[c] Source: Sichuan Provincial Research Institute of Animal Husbandry and Veterinary Science.

Table 4. Effect of poplar leaf meal on egg production.

	Treatment			
	I	II	III	IV
Diet				
Base diet (%)	97	95	93	100
Poplar leaf meal (%)	3	5	7	0
Egg production rate (%)				
30 days before experiment	58.4	58.3	57.6	57.8
60 days experiment	67.4	62.5	64.5	60.5
30 days after experiment	62.6	61.3	60.6	60.2
Egg weight (g)	55.1	54.5	54.6	53.4
Fertility of eggs (%)	95.5	95.6	95.4	94.7
Hatchability of fertilized eggs (%)	89.7	92.2	89.3	89.5

Source: Li and Zhou (1982).

Table 5. Pig-feeding experiment.

	Treatment		
	I	II	III
Concentrate feeds (%)	90	90	90
Wheat bran (%)	10	5	—
Locust leaf meal (%)	—	5	10
Daily live weight gain (g)	532.4	590.2	520.9
Feed conversion rate	4.7	4.6	4.8

Source: Zhao et al. (1975).

Veterinary Science by using the vitro method described by Zhang and Nie (1986). Results indicate that locust tree leaf meal could be used at a 5% level in pig diets, replacing wheat bran, which is a common feed ingredient in China and often in short supply (Table 5).

Shrubs

Shrubs are widely distributed in China. In Guizhou Province, southern China, there are over 1 300 kinds of shrubs (Li 1988). The leaves and tender twigs of shrubs are rich in protein, vitamins, and minerals, but their nutritive value varies with maturity (Table 6).

Table 6. Nutrient content of some shrubs (% dry matter basis).

Species	CP	EE	CF	NFE	Ash
Lespedeza bicolor[a]	22.2	3.1	17.0	48.1	9.6
Caragana stanophylla[b]					
Early spring	10.6	6.2	42.3	37.5	3.4
Vegetative	18.7	5.9	38.1	31.0	6.2
Flower bud	23.8	4.8	34.5	25.3	11.8
Caragana pygmaca[b]					
Dry season	11.6	4.9	46.4	34.6	2.5
Strong budding	22.6	3.5	31.1	37.3	5.5
Late blooming	17.1	5.2	40.4	28.9	4.3

Note: CP, crude protein; EE, ether extract; CF, crude fibre; NFE, nitrogen-free extract.

[a] Source: Linmao (1985a).

[b] Source: Linmao (1985b).

Table 7. Pig-feeding test with leucaena leaf meal.

	Wong (1985)		Lizi (1986)		
	I	II	I	II	III
Diet					
Concentrate (%)	100	95	100	90	80
Leucaena leaf meal (%)	0	5	0	10	20
Daily live weight gain (g)	656.5	659.7	520	578	483

Shrubs are mainly used by grazing animals, especially goats. Recently, some have been processed into leaf meal and fed to pigs and other monogastric animals. In 1988, an animal husbandry station in Hebei Province used *Lespedeza* leaf meal to replace wheat bran in the diets of pigs and laying hens. During a 91-day pig-feeding experiment, the daily weight gain of the test group was 675 g; that of the control group was only 470 g. In a feeding experiment with laying hens, the control diet contained 10% wheat bran and the test diet contained 2% wheat bran and 8% *Lespedeza* leaf meal. The egg production rate of the test group was 3% higher than that of the control group over the 89-day experimental period. The researchers concluded that *Lespedeza* leaf meal was equal in value to wheat bran.

Wang (1985) and Lizi (1986) fed *Leucaena leucocephala* to pigs. Their results were nearly identical. According to Lizi, *Leucaena* can be included in the diet up to a level of 10%. There were no toxic symptoms at even 20% *Leucaena* (Table 7).

Use of shrubs and tree fodders

Grazing

Grazing by ruminants is the traditional way of using shrubs and tree leaves and remains the most common in areas where animal raising is the people's main means of livelihood. Most of these areas are in northern and western China, and in the Qing-Zang and Yun-Gui high plateaus. There are 286.7×10^6 ha of grassland in northern and western China, with about 220×10^6 ha available area and 100 million goats and sheep. The area is large but generally dry and cold. Shrubs and tree leaves are one of the main foods of goats and sheep. *Caragana*, *Calligonum*, and *Hedysarum* are important shrubs that are now planted in these areas.

In southern China, grazing districts are concentrated in the mountainous area. There are 46×10^6 ha of tropical and subtropical grassland, carrying about 26 million goats and 10 million sheep (Li 1988). Because of the wet, warm climate, the shrubs and trees grow very well. The farmers are mainly engaged in agriculture, but also traditionally raise goats and cattle in nearby woodlands and on grassy slopes. Because these grasslands are scattered among crop lands, farmers often have to tether their animals or hire someone to herd them to the mountains for grazing in the morning, returning late in the evening. Here, shrubs such as *Bauhinia championi*, *Coriaria sinica*, *Lespedeza* spp., *Rhododendron simsii*, *Spiraea pubescens*, *Rosa* spp., *Rhus chinensis*, and *Rubus* spp. are still abundant.

Cut-and-carry feeding

In agricultural areas and near large cities, the demand for meat and milk is high. People can earn more money in the dairy market than by planting crops. Therefore, dairy cattle (generally crossbred cows that can also help plow the field) and dairy goats are being developed in some rural areas where there is organized milk collection. Farmers prefer to confine these animals in a shed and cut and collect grasses and shrubs as feed. The extra work involved in finding and cutting forage for these animals brings considerable benefit to the farmers.

Processing into leaf meal

The practice of processing tree fodders into leaf meal and adding them to standard diets is developing rapidly in China. In the case of pine needle processing, the first plant was established in 1980. By June 1984, 8 plants were in production; 20 other plants are being established. To set up a 300 to 500 t capacity processing plant, about 100 000 CNY must be invested (in July 1989, 3.5 Chinese yuan [CNY] = 1 United States dollar [USD]). However, the net profit in 1 year could completely return the capital invested (Zhou 1986).

In the Yaobian Autonomous District of Jiling Province, the feed company only produced 5.35 t of leaf meal in 1981; however, the quantity reached 386 t in 1982 and 436.1 t in 1983 (Yanbian Siliaogongsi 1984). In a suburb of Beijing, since 1975, more than 6.5×10^6 kg of amorpha and locust tree leaves have been collected and added to animal feeds at 5–10% (Beijing Siliaogongsi 1979).

In Bazong County, Sichuan Province, the forage and feed station set up a small processing plant at a township in 1986 and rented it to a farmer. This farmer produced 132 t of locust tree leaf meal in 1988 and sold it to the feed company of Bazong. The income the farmer accumulated from running this business from June to September was substantial. Bazong County is now trying to establish more of these plants; leaf meal production could be increased at least 20-fold.

The importance of tree fodders

The importance of developing livestock is justified by the growing demand from the human population of China, which now stands at about 1.1 billion (10^9). The demand for meat and milk is increasing very quickly. At the same time, the arable land, especially for grain production, is decreasing (Table 8). Lack of feed has already become a limiting factor in animal production. However, if natural grasslands or grassy slopes are converted into arable land, ecological problems, such as soil erosion, will become even more serious.

Developing and using tree fodders is one important way of solving these

Table 8. Cropping area in China from 1975 to 1985 ($\times 10^6$ ha).

	1975	1980	1982	1984	1985
Total cropping area	149.6	146.4	144.8	144.2	143.6
Proportion (%)	80.9	80.1	78.4	78.3	75.8

problems. Tree fodders could be produced on marginal lands, combined with forest, or in areas not useful for grain production. Trees can also help to prevent soil erosion and sustain land use. Fodders could be used both as ruminant feed and as a feed ingredient for monogastric animals. Moreover, many tree fodders have not been fully explored. The Chinese government is now giving more attention to this field. Some grassland-improvement programs and herbivore-development projects are being initiated. A law protecting grasslands has been passed and, in many districts, cropping on a slope over 25° is prohibited. Most natural grassland and grass slopes have been assigned to farm households. Therefore, increased animal production based on shrubs and tree fodders is expected.

Toxic substances

Research on toxic substances is very rare in China, but toxic plants do create some problems for animals. In the mountainous areas of Sichuan and other provinces, for example, many cattle die between April and mid-May. The Provincial Research Institute of Animal Husbandry and Veterinary Science of Sichuan found that this was because the animal ate leaves from *Quercus* spp., which is widely distributed. Some experiments have also been conducted to study the effects of tannic acid. Much more research is required on toxic plants, the toxins involved, and ways to reduce their effects.

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Discussion

Session IV was devoted to presenting the issues and problems concerning shrubs and tree fodders on a country-by-country basis. Thirteen papers were presented.

The first paper presented the situation in Africa with reference to the five major agroecological zones: humid, subhumid, semi-arid, arid, and montane. It was emphasized that shrubs and tree fodders play a very important role in livestock production as well as within the farming systems. Special reference was made to browse, which was generally richer in protein and minerals. Its use resulted in increased intake and survivability, especially during the dry season. Increased cultivation of fodder trees in agroforestry systems and the need for more research were emphasized.

Discussion centered on the ownership of browse and methods for its utilization. Questions were also raised about varying soil conditions and the problems associated with plant growth in these situations.

The second paper discussed the potential of tree fodders for animals in Central America. Particular emphasis was given to the use of *Erythrina* spp. and *Gliricidia sepium*. Data from five agroforestry systems clearly indicated that forage biomass yield was a function of the pruning interval of shade trees, spacing, and the age of the plantation. Total biomass yield increased as the pruning frequency decreased. The results of several feeding trials with small ruminants and cattle were presented; together, they demonstrated beneficial responses to shrubs and tree fodders.

Discussion focused on the importance of protein degradation in the rumen and the extent of this with some of the feed materials used. Associated issues included the solubility of the protein, factors affecting solubility, and the role of tannins.

The third paper reported on the acute feed shortages, relative to livestock population, in Pakistan. Interest in shrub and tree fodders is relatively recent, but it is receiving increased attention. More investigations are needed on the nutritive value of many of these feeds as well as their use for individual ruminants. During discussion, suggestions were made on the importance of assessing various fiber fractions, and mineral and tannin contents.

The fourth paper discussed agrosilvipasture systems in India, emphasizing integrating trees, woody perennials, and grasses with crop farming to ensure stability, high productivity, improved soil fertility, and increased fodder supply for ruminants. Various shrub and grass species have been identified for the different agroclimatic regions of India to enhance biomass production and meet the increasing demands for forage and fuelwood. Discussion focused mainly on severe overgrazing, the degradation of rangeland, and the effects of fodder trees, grasses, legumes, and technology transfer.

The following four papers in this session also discussed the South Asian situation. As in Pakistan, the paper from India demonstrated a huge feed deficit. Current trends in population growth indicate that the goat population is increasing at a much more rapid rate than the sheep population, reflecting increasing dependence on shrubs and tree fodders. Considerable data were presented on the use of various feed materials, especially in comparative studies between sheep and goats.

Discussion focused on the reasons for the increasing goat population. It was suggested that the increase in an indication of the wide use of marginal land and problems of land degradation. The mechanisms of extending technology packages to farmers were also discussed.

The papers from Nepal, Bangladesh, and Sri Lanka reflected a very low level of information about shrubs and tree fodders. However, it is equally clear that farmers in all of these countries traditionally give tree fodders to their animals. All presenters emphasized the need for more research and development efforts to increase the current low level of information.

The discussion following the papers from Bangladesh and Sri Lanka emphasized the importance of assessing the intake and digestibility of browse species, and of cooperating in and sharing this research. The importance of strategic supplementation and, in particular, the potential value of leguminous fodders was also discussed.

Particular discussion focused on the methodology of assessing the importance of fodder trees for individual environments. The question was whether there should be intensive surveys to assess current feeding practices, limitations, and constraints, and, at the same time, studies exploring the potential for introducing more improved varieties. There was general consensus that these aspects are important in developing technology packages of value to farmers.

The next paper discussed the use of shrubs and tree fodders in Thailand. It was indicated that many of these feeds, notably *Leucaena* and cassava leaves, are widely fed to ruminants as protein supplements, especially when feed is scarce, such as during the long dry season. The results of several trials clearly indicated that these feeds were beneficial. Limited data were also given on *Gliricidia* leaf, water hyacinth, and cowpea residue.

The paper from Malaysia highlighted the diversity of shrub and tree species, including a reference to oil palm. Data were provided on the more commonly used shrub and tree fodders, of which *Leucaena*, *Gliricidia*, and *Cajanus cajan* were prominent.

Discussion following this paper centered on utilizing of trunks and fronds of oil palms, extracting nutrients, and the sustainability of such a system. Also discussed were various methodological issues that need to be defined to support growing fodder trees for intensive production.

In Indonesia, it was clear that shrub and tree fodders are traditionally and intensively used by farmers. Government efforts have promoted the wide use of shrubs and tree fodders. In Indonesia, these feeds evidently need more promotion by extension personnel.

The following paper concerned the Philippines, where shrub and trees have long been recognized as important components of farming systems. Particular reference was made to the experiences with *Leucaena* in agroforestry systems and to supplying fodder for ruminants. *Leucaena* is used as a feed in grazing systems and as a supplement to rice straw and maize silage. Several studies on the use of *Leucaena* were summarized. This presentation further underlined the importance of biodiversity as a way of reducing the risk inherent in depending on one particular fodder tree, such as *Leucaena*.

The final paper in the session was from China; it gave a comprehensive picture of the value of shrub and tree fodders in this country. More than 400 species of shrub and trees are cultivated in China, with an annual yield of more than 500 $\times 10^6$ t. The limited data presented concerned the use of *Pinus* leaf meal for poultry and *Robinia pseudoacacia* and *Leucaena* for pigs. The paper also referred to the considerable potential for using these feeds with ruminants.

Session V

Processing, Methodology, and Economics

Opportunities for processing and using shrubs and tree fodders

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Abstract — *The development of appropriate processing methods for the intensive use of fallen dry tree leaves is discussed in view of the available biomass and chronic feed deficit situation in India. Grinding increases the bulk density of fallen tree leaves 30 times. Improved bulk density and easy flow characteristics of the ground leaves simplify and make processing more economic. Studies on grinding leaves and on steam pelleting of feeds containing fallen tree leaves have given promising results. The formulation and processing of complete feeds in mash or pelleted form, using fallen tree leaves as a roughage source, was successfully tested with sheep. Because knowledge on the use of fallen tree leaves is limited, intensive, long-term nutritional studies with on-farm testing and evaluation, the development of simple mechanical devices for the collection of leaves from forests, the fabrication of small steam-pelleting units, and the establishment of suitable grinding mills are important priorities.*

Résumé — *L'auteur discute de la mise au point de bonnes méthodes de transformation, aux fins d'usage intensif, des feuilles d'arbre mortes à la lumière de la biomasse disponible et de la situation déficitaire chronique des fourrages en Inde. Le broyage accroît trente fois la densité de la masse des feuilles mortes. Une meilleure densité et des caractéristiques qui faciliteraient leur passage dans les machines simplifieraient leur transformation et la rendraient plus économique. Les études sur le broyage des feuilles et sur la granulation à la vapeur de fourrages contenant des feuilles mortes ont donné des résultats encourageants. La formulation et la transformation de fourrages complets sous forme de pâtée ou de granules, dans lesquels les feuilles mortes fournissent le fourrage grossier, ont été testées avec succès pour le mouton. Parce les connaissances sur l'emploi des feuilles mortes sont restreintes, il s'impose en priorité de réaliser des études nutritionnelles intensives et de longue durée accompagnées d'essais et d'évaluations en ferme, de mettre au point des machines simples de collecte des feuilles dans les forêts, de fabriquer de petites presses à granuler à la vapeur et d'aménager les moulins à broyer indiqués.*

Resumen — *Se estudia la preparación de métodos de procesamiento adecuados para usar intensivamente las hojas secas caídas de los árboles, en vista del déficit crónico en materia alimenticia y biomasa disponible en la India. La molienda incrementa 30 veces la densidad aparente de las hojas caídas de árboles. El aumento de densidad aparente y la facilidad de extracción de las hojas del suelo, simplifican y economizan el procesamiento. Se han obtenido resultados promisorios de los estudios efectuados con hojas molidas y forrajes que contienen hojas caídas de árboles comprimidas al vapor. La formulación y el procesamiento de piensos comprimidos o* *prensados, usando hojas caídas de árboles como fuente de forraje grosero, dio excelentes resultados en las ovejas. Debido a la limitada información que se tiene respecto al uso de hojas caídas de árboles, debe darse preferencia a estudios sobre alimentación intensiva de animales, a largo plazo, con verificación y evaluación práctica (en la granja), así como la creación de dispositivos mecánicos simples para recolectar hojas de bosques, la fabricación de equipos pequeños de compresión al vapor, y la instalación de molinos de muelas apropiados.*

Introduction

India accounts for about 15% of the world's livestock population. The projected green and dry fodder requirements for the year 2000 are 1 136 × 10^6 and 949 × 10^6 t, respectively (Punjab Singh 1988). Currently, the feed and fodder resources of India can meet only 46.6% of the requirement of the livestock population of over 400 million. Of the country's cropped area, 6.9 × 10^6 ha (4.4%) is under fodder crops and there is hardly any scope for expansion of fodder cultivation because of pressure on agricultural land for food and cash crops. The forest grazing resources are also dwindling at a rate of about 1.5 × 10^6 ha/year. The solution, therefore, lies in maximizing the use of nonconventional feed resources such as shrub and tree fodders, and fibrous agricultural residues.

The use of shrubs and tree fodders in India has been discussed in detail by Raghavan (this volume). There is also about 43 × 10^6 t of fallen forest tree leaves that, if processed, could be used by the animals. Every year, during autumn, huge quantities of tree leaves become available. Punj (1983) has also reported that there is 300–350 × 10^6 t/year of unused dry, fallen, forest leaves and forest grass from 67.4 × 10^6 ha of forest. In addition to fallen tree leaves, enormous quantities of tree leaves are available because of the felling of the trees from the forests and from the Farm Forestry area. The planting of trees by the farmers alternate to crop farming has recently increased significantly in India.

Fallen dry leaves from forests and various tree plantations represent a potentially important source of livestock feed, if appropriate processing technology is developed and adopted. This paper focuses on these aspects.

Processing methods

About 18.8 × 10^6 t of fallen teak leaves (*Tectona grandis*; ICAR 1985), 0.5 × 10^6 t of fallen mango leaves (*Mangifera indica*; College of Veterinary Science 1983), and about 23.8 × 10^6 t of fallen mixed dry tree leaves (College of Veterinary Science 1981) are produced every year. Currently, the fallen tree leaves are not used and mostly either burn in forest fire accidents during summer or decay naturally. The Indian Department of Forestry prohibits the lopping of forest trees such as teak, sal, mahua, etc.; however, they have no objection to the removal of fallen leaves. Fallen leaves are not consumed by the animals as they are dry and unpalatable. These materials are nutritionally inferior to even low-grade crop residues (Table 1), and the animals cannot use them unless they are suitably processed. Considering the huge availability of this biomass and the serious shortage of feedstuffs in India, there is an urgent need to develop appropriate processing technologies.

Table 1. Chemical composition of fallen dry leaves (%, dry matter basis).

Botanical name (common name)	CP	EE	CF	NFE	Total ash	Ca	P	Source
Tectona grandis (teak)	4.9	3.1	20.3	51.5	20.2	2.4	0.1	V.A. Reddy and M.R. Reddy (1984)
Mangifera indica (mango)	4.0	2.8	25.7	43.2	24.3	2.4	0.5	Reddy et al. (1984)
Eucalyptus spp. (eucalyptus)	3.4	2.9	29.9	47.8	16.1	—	—	Garudoji and Reddy (1986)
Mixed leaves from forest[a]	10.1	4.7	25.3	48.5	11.4	2.6	0.6	Reddy et al. (1984)
Madhuca indica (mahua)	10.0	2.3	20.5	56.8	10.5	—	—	Punj (1983)
Bengalensis glomerales (Banyan)	5.2	3.3	20.1	45.6	24.9	2.0	0.2	Swamy (1988)

Note: CP, crude protein; EE, ether extract; CF, crude fibre; NFE, nitrogen-free extract.

[a] *Diospyos meclonoxylon* (beedi), 21%; *Ficus bengalensis* and *F. glomerales* (ficus), 43%; *Butea frondosa* (moduga), 11%; *Azadirachta indica* (neem), 1%; miscellaneous, 24%.

Processing methods like grinding in hammer mills or steam pelleting can be used with fallen dry tree leaves. These leaves are lighter than crop residues; their bulk density is 11 kg/m^3, compared with 60–80 kg/m^3 for chopped cereal straws. After grinding, the bulk density of the leaves increases more than 30 times. The bulk density of ground tree leaves is 370 kg/m^3, compared with 100–150 kg/m^3 for cereal straws. This clearly indicates that light tree leaves can be economically transported, after grinding, from where they are available to where they are needed. Hammer mill production performance increased markedly when fallen tree leaves were ground (500 kg/h), compared with cereal straws like sorghum straw (200 kg/h). Thus, size reduction of fallen dry tree leaves is easy compared with fibrous crop residues. The fibre of the fallen tree leaves is more brittle and less resistant than the cereal straws and, hence, the performance of the hammer mill increases markedly, while reducing the cost of grinding. The ground tree leaves may be incorporated in various feed formulae and commercial feed compounds at appropriate levels (G.V.N. Reddy and M.R. Reddy 1984, 1986). Fallen tree leaves cannot, however, form the sole source of feed: they have a poor palatability and a low nutritional value (Reddy et al. 1984).

Steam pelleting is an important processing method that can be economically applied for processing feeds containing fallen dry tree leaves. The pelleting process improves the acceptability and use of low-quality roughages (Hale and Theurer 1972), controls dustiness, and prevents segregation of ground particles. Pelleting also improves the density (Reddy 1986) and keeping quality of feedstuffs. The increase in bulk density as a result of pelleting mash feeds ranged from 52 to 137%, depending on the level and type of crop residues used in the ration (Reddy 1986). The advantages of pelleting are more pronounced in fibrous roughages than in concentrate feeds (Hale and Theurer 1972).

Because of the high density of the ground mash, the fallen tree leaf powder is free flowing in the processing machinery, especially in conveying systems, allowing easy and economic processing. Ground crop residues, however, do not flow easily because of low density and flat particle shape. This adversely affects the production performance of the processing machines and increases the cost of processing (Reddy 1988).

High levels of fallen dry tree leaves (up to 70%) can be used in the formulation and processing of pelleted complete diets. These feeds were successfully fed to sheep without any adverse effects (G.V.N. Reddy and M.R. Reddy 1984). Preliminary investigations (G.V.N. Reddy and M.R. Reddy 1984, 1986) have revealed that economic rations for small ruminants could be processed into pelleted form using fallen tree leaves as the sole source of roughage.

It has been reported that the fibre of fallen dry tree leaves is less resistant and easy to grind and pellet, resulting in more feed production per hour and reduced processing cost (Reddy 1988). The rate of pelleted feed production ranged from 300 kg/h (68% dry mixed grass ration) to 857 kg/h (70% fallen teak leaves ration) for a pellet mill with a capacity of 1 000 kg/h for a conventional concentrate mixture (Reddy 1988). Physical characteristics like bulk density, particle size, particle shape, molasses absorbability, grinding performance, pelletability, etc., of fallen tree leaves are more favourable for economic processing compared with crop residues (Table 2). Thus, grinding and steam pelleting of fallen dry tree leaves is an easy and economical processing method, and can be used to manufacture low-cost livestock feeds.

Table 2. Physical characteristics of fallen tree leaves and crop residues.

Characteristic	Fallen dry leaves (mango)	Sorgham straw	Corn straw	Corn cobs	Peanut hulls
Bulk density (kg/m^3)	11	82[a]	59[a]	148	104
Bulk density (ground material) (kg/m^3)[b]	370	133	103	322	185
Hammer mill performance (kg/h)[b]	500	200	150	150	300
Particle size (µm)[b]	343	584	659	1 148	851
Modulus of uniformity[c]	1:5:4	2:5:3	3:5:2	6:2:2	4:4:2
Modulus of fineness[b]	2.94	3.37	3.66	4.97	4.22
Molasses absorbability (%)[b]	52	40	52	28	30
Pellatability[b]	Medium	Very low	Very low	Very low	Medium

[a] Chopped.

[b] Material ground in a hammer mill (40 horsepower) through an 8-mm sieve.

[c] Proportion of coarse, medium, and fine particles in a ground sample.

Use of processed tree leaves

Fallen mixed tree leaves in the forest were ground in a hammer mill using a 5-mm sieve and the ground mash was the sole feed given to adult Nellore sheep (Reddy et al. 1984). The animals consumed an average of 2.44 kg dry matter/100 kg body weight (58.2 g/unit metabolic body weight) and lost weight at a rate of 100 g/day during the experiment. The nutritive value of the fallen forest mixed leaves (*Ficus* spp., *Butea frondosa* [moduga], *Azadirachta indica* [neem], etc.) was 2.3% digestible crude protein (DCP) and 26.7% total digestible nutrients (TDN). The animals were on negative nitrogen, calcium, and phosphorus balances, indicating that the fallen tree leaves cannot form the sole feed.

To improve the feeding quality of the dry tree leaves, ground teak leaves were added at 0, 25, 50, and 100% as the roughage source, replacing conventional roughage. Dry, mixed grass and four complete diets were formulated and processed into pelleted form. The four pelleted feeds containing various levels of fallen teak leaves were fed to Nellore rams to assess palatability, nutrient digestibility, and use. The results of this study (Table 3) indicated that the voluntary dry matter intake (DMI) increased as the level of ground teak leaves in the feed increased. However, the digestibility of dry matter and crude fibre significantly ($P < 0.01$) decreased with increased teak levels. DCP and TDN reduced from 8.4 to 7.2% and from 55.8 to 50.8%, respectively, when mixed grass was completely replaced with teak leaves as the sole source (70% of the complete feed) of roughage. However, there was

Table 3. Value of fallen dry teak leaves in four complete pelleted feeds for sheep.

	1	2	3	4
% composition				
Dry mixed grass	70.0	52.5	35.0	—
Fallen dry teak leaves	—	17.5	35.0	70.0
Peanut meal	9.5	9.5	9.5	9.5
Tapioca chips	5.0	5.0	5.0	5.0
Cage layer droppings (dried)	5.0	5.0	5.0	5.0
Molasses	8.5	8.5	8.5	8.5
Mineral mixture	1.0	1.0	1.0	1.0
Urea	0.5	0.5	0.5	0.5
Common salt Rovimix[a]	0.5	0.5	0.5	0.5
Nutritive value[b]				
DMI/100 kg body weight (kg)	3.7	4.0	4.2	4.6
DMI/kg$^{0.75}$ (g)	85.9	93.3	97.1	106.7
DCP intake/kg$^{0.75}$ (g)	8.6	7.5	8.8	8.6
ME intake/kg$^{0.75}$ (kJ)	723.8	790.8	774.0	820.1
TVFA (mequiv./L)	102.3	—	—	96.5
DCP (%)	8.4	7.4	7.4	7.2
TDN (%)	55.8	55.7	52.7	50.8

[a] Rovimix: A and D$_3$ vitamin supplement with 40 000 IU/g vitamin A and 5 000 IU/g vitamin D$_3$ was added at 10 g/100 kg of feed.

[b] DMI, dry matter intake; DCP, digestible crude protein; ME, metabolizable energy; TVFA, total volatile fatty acids; TDN, total digestible nutrients.

little variation in the nutritive quality of the feed when 25–50% mixed grass was replaced with ground fallen teak leaves. The addition of teak leaves to the complete feed did not affect nitrogen, calcium, and phosphorus balances. The cost of processing the complete feeds decreased significantly as the level of teak leaves increased.

Mango leaves were successfully used as a roughage source in complete feeds of sheep (G.V.N. Reddy and M.R. Reddy 1984). The fallen dry mango leaves were ground in a hammer mill using a 5-mm sieve. The ground leaves were added at 30 and 60%, replacing dry mixed grass as the roughage source and were processed into mash and pelleted forms. These four complete feeds (Table 4) were tested on 24 Nellore rams. DMI was more ($P < 0.01$) with the pelleted feed than with the corresponding mash. Including fallen dry mango leaves as the roughage source did not affect DMI. DCP was higher ($P < 0.01$) with the pelleted feeds. Pelleting also improved in both feeds containing mango leaves. However, TDN decreased as the level of mango leaves increased from 30 to 60%; this may be due to the high tannin content of mango leaves. Fallen mango tree leaves contain 9.35% tannin; steam pelleting of the mash feed markedly reduced this tannin content. This study indicates that fallen dry mango leaves could be safely used in complete feeds at a level of 30% without any adverse effects. However, pelleting complete mash feeds may further improve nutrient use.

To overcome the tannin effect of fallen mango leaves, calcium oxide (CaO) or

Table 4. Value of fallen dry mango leaves as the roughage source in pelleted and mash feeds for sheep.

	Mash 1	Pellet 2	Mash 3	Pellet 4
	% composition			
Fallen mango leaves (dried)	30.0	30.0	60.0	60.0
Dry mixed grass	30.0	30.0	—	—
Peanut meal	10.0	10.0	10.0	10.0
Cage layer droppings (dried)	8.5	8.5	8.5	8.5
Wheat bran	10.0	10.0	10.0	10.0
Molasses	10.0	10.0	10.0	10.0
Mineral mixture	1.0	1.0	1.0	1.0
Common salt Rovimix[a]	0.5	0.5	0.5	0.5
	Nutritive value[b]			
DMI/100 kg body weight (kg)	3.3ab	3.9bc	3.0a	3.6b
DMI/kg$^{0.75}$ (g)	81.9g	95.6g	74.9e	87.6f
DCP intake/kg$^{0.75}$ (g)	4.7	6.0	4.5	5.6
ME intake/kg$^{0.75}$ (kJ)	464.4	506.3	389.1	418.4
Tannins (g%)	3.1	1.9	6.2	4.4
DCP (%)	5.7a	6.2c	5.9b	6.4c
TDN (%)	46.7c	50.7d	39.0a	42.1b

Note: Values in the same column followed by different letters differ significantly (a, b, c, d, $P < 0.01$; e, f, g, $P < 0.05$).

[a] Rovimix: A and D_3 supplement with 40 000 IU/g vitamin A and 50 000 IU/g vitamin D_3 was added at 10 g/100 kg of feed.

[b] DMI, dry matter intake; DCP, digestible crude protein; ME, metabolizable energy; TDN, total digestible nutrients.

Table 5. Effect of urea and calcium oxide (CaO) in five mash feeds for sheep using fallen dry mango leaves as the roughage source.

	1	2	3	4	5
	% composition				
Dry mixed grass	50.0	—	—	—	—
Fallen dry mango leaves	—	50.0	—	50.0	50.0
Urea	—	—	—	1.0	1.0
CaO	—	—	0.5	—	0.5
Cage layer droppings (dried)	8.5	8.5	8.5	8.5	8.5
Peanut meal	17.0	15.0	15.0	8.0	8.0
Rice bran	13.0	15.0	14.5	21.0	20.5
Molasses	10.0	10.0	10.0	10.0	10.0
Mineral mixture	1.0	1.0	1.0	1.0	1.0
Common salt Rovimix[a]	0.5	0.5	0.5	0.5	0.5
	Nutritive value[b]				
DMI/100 kg body weight (kg)	4.3a	3.3bc	3.7ab	2.8c	3.7ab
DMI/kg$^{0.75}$ (g)	104.0	82.0	91.0	70.0	89.0
DCP intake/kg$^{0.75}$ (g)	6.3	4.9	5.7	3.1	4.8
ME intake/kg$^{0.75}$ (kJ)	707.1	523.0	615.0	410.0	569.0
DCP (%)	6.1a	5.8ab	6.1a	5.3b	5.5a
TDN (%)	45.0a	42.0ab	44.6a	38.8b	42.2ab

Note: Values in the same column followed by different letters differ significantly ($P < 0.05$).

[a] Rovimix: A and D_3 supplement with 40 000 IU/g vitamin A and 5 000 IU/g vitamin D_3 was added at 10 g/100 kg of feed.

[b] DMI, dry matter intake; DCP, digestible crude protein; ME, metabolizable energy; TDN, total digestible nutrients.

urea were added to the feeds. Five complete feeds were formulated using dry mixed grass (control) and fallen dry mango leaves as the sole roughage source (50%), and the feeds were processed into mash form (Table 5). The effects of 0.5% CaO and 1% urea were evaluated in a metabolic study on 30 adult Nellore rams.

The feed containing CaO improved the use of mango leaves compared with the control. The study indicated that fallen mango leaves could be safely used as the sole source of roughage in complete feeds and that CaO, rather than urea, will improve the use of the leaves. Urea is a less effective nitrogen source when fallen mango leaves are used as roughage.

Economic benefits

The cost of processing complete feeds containing fallen tree leaves or dry mixed grass (Table 6) was calculated on a pilot-plant basis, considering both fixed charges (depreciation on building and machinery, interest on block investment, and maintenance) and direct charges (cost of power, labour, operators, etc.). The total cost of processing complete mash feeds containing dry fallen tree leaves as the sole source of roughage was 7.1 INR/q, compared with 8.0 INR/q for the feed containing dry mixed grass (1 q = 100 kg; in June 1989, 15.4 Indian rupees [INR] = 1 United States dollar). The processing cost of pelleted complete feeds containing tree leaves ranged from 8.6 to 16.0 INR/q with production rates of 6.1 to 8.6 q/h,

Table 6. Economic benefits of using fallen leaves.

Roughage component of complete feed	Type of processing	Rate of feed production (g/h)[a]	Processing cost (INR/q)[b]	Total cost of the feed (INR/q)[b]
Dry mixed grass (70%)	Pellet	5.0	12.4	61.0
Dry mixed grass (52.5%) + teak leaves (17.5%)	Pellet	5.1	12.0	58.0
Dry mixed grass (35%) + teak leaves (35%)	Pellet	5.5	11.6	55.0
Teak leaves (70%)	Pellet	8.6	8.6	46.7
Mango leaves (30%) + dry mixed grass (30%)	Mash	—	8.0	61.5
Mango leaves (30%) + dry mixed grass (30%)	Pellet	6.1	16.4	69.9
Mango leaves (60%)	Mash	—	7.1	56.2
Mango leaves (60%)	Pellet	7.7	16.0	65.0
Mango leaves (50%)	Mash	7.5	7.2	59.5
Dry mixed grass (50%)	Mash	5.1	8.0	85.3

Source: V.A. Reddy and M.R. Reddy (1984) (first four entries), G.V.N. Reddy and M.R. Reddy (1984) (last six entries).

[a] 1 q = 100 kg.

[b] In June 1989, 15.4 Indian rupees [INR] = 1 United States dollar. 1 q = 100 kg.

compared with 12.4 to 16.4 INR/q with production rates of 5.0 to 6.1 q/h for the feeds containing dry mixed grass. There was a marked increase in pellet mill performance and a considerable reduction in the processing cost with diets containing fallen tree leaves compared with diets containing dry mixed grass. These studies clearly indicate that fallen tree leaves can be economically ground and pelleted compared with fibrous roughages such as dry mixed grass.

The costs of the diets were calculated considering the existing market rates of the ingredients used in the formulae (Table 6). The total cost of the non-cereal-based diets (including processing cost) using fallen tree leaves ranged from 46.7 INR/q (70% fallen teak leaves) to 59.5 INR/q (50% fallen mango leaves), compared with 61.0–85.3 INR/q for the feed containing 50–70% dry mixed grass. Replacing dry mixed grass with fallen tree leaves resulted in a significantly reduced total cost of the feeds, without affecting nutritive quality and animal performance. These studies clearly demonstrated the economic benefits of processing and using fallen tree leaves in the diets of small ruminants. However, long-term studies on meat and milk production using optimum levels of fallen tree leaves, along with on-farm testing and evaluation, must still be performed.

Constraints

Many constraints exist concerning processing.

- Inadequate data exist on the nutritional quality, levels that can be incorporated in the livestock feed, and pretreatments (physical and chemical) to improve nutritive quality.
- Practical leaf-collection methods from the forests must be developed.

- Problems of transportation and handling of these light materials must be solved.
- There is a lack of initiative and will from the government, cooperatives, and other related agencies to use these feed resources.

Strategy for action

Realizing the prevailing situation of livestock feed resources and with the primary objective of expanding the use of nonconventional feed resources such as fallen tree leaves, realistic development strategies are urgently required. The following steps must be undertaken.

- Simple and cheap mechanical devices must be developed to collect the fallen tree leaves from forests.
- Portable bailing units that can increase the density of the light tree leaves, allowing economic transportation, are needed.
- Suitable grinding machines and hammer mills must be established in the forest area.
- Steam pelleting units must be made locally.
- Long-range, intensive studies on the use of tree leaves for meat and milk production, including on-farm testing and economic evaluation, are needed.

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Development and evaluation of agroforestry systems for fodder production

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Abstract *— Agroforestry, which integrates tree management, food production, and environmental conservation, has a potential role in rural development. This paper outlines how agroforestry systems that incorporate fodder production as a main objective can be developed. It focuses on the basic criteria to use, species selection, management practices, and the advantages and constraints involved. A method of evaluation and strategies for future consideration are also discussed.*

Résumé *— L'agroforesterie, qui associe la gestion des arbres à la production alimentaire et à la conservation de l'environnement, a, potentiellement, un rôle à jouer dans le développement rural. Les auteurs donnent d'une manière générale comment créer des systèmes agroforestiers dont la production de fourrages est le principal objectif. Ils s'attachent aux critères à employer pour choisir les espèces, aux méthodes de gestion et aux avantages prévues et aux obstacles à prévoir. Ils discutent également d'une méthode d'évaluation et de stratégies à envisager.*

Resumen *— La agroforestación, que abarca la explotación de árboles, producción alimenticia y protección del medio ambiente, desempeña un papel importante en el desarrollo rural. Este trabajo expone de qué manera pueden desarrollarse los sistemas agroforestales para los que la producción de forrajes es el principal objetivo. Se concentra en los criterios básicos de los regímenes de explotación, selección de especies, y las ventajas y limitaciones que involucran. También se efectuó el análisis de un método de evaluación y estrategias para su posterior consideración.*

Introduction

The need to increase food production to meet the demand of rapid population increases is a major problem faced in most parts of the world, especially in developing countries. The problem has been aggravated by shortages of arable land for agricultural activities because of biophysical and environmental constraints.

One approach to solving the problem of food supply has been to formulate appropriate technologies for various land-development strategies. Our increased understanding of tropical environments (social and ecological), based on practical experience and scientific knowledge in related disciplines (agriculture, forestry, ecology, soil science, and rural economics), has led to alternative approaches to land development.

Consequently, because the role and value of trees and other woody perennials is being increasingly recognized in the everyday life of the rural population, agroforestry systems have been developed and described (e.g., Escalante 1985; Johnson and Nair 1985; Michon et al. 1986; Poschen 1986). Common agroforestry systems include agrisilvicultural (trees and crops), silvopastoral (trees and livestock), and agrisilvipastoral (trees, crops, and livestock) systems.

For fodder production, silvipastoral and agrisilvipastoral systems are predominant. Torres (1983) recognizes these systems as "animal agroforestry"; a generic name for all agroforestry systems that include animals as a component. One of the most significant developments in "animal agroforestry" is the expanding role of trees as a component in fodder production. This development has largely contributed to meeting the growing demand for food and, subsequently, enhanced the socioeconomic condition of the rural population.

This paper describes the development and evaluation of some agroforestry systems for fodder production, with the main emphasis on the role of trees in fodder production. A method of evaluation and strategies for future consideration are also described.

Criteria for development

Planning for development must be made at all levels of operation in agroforestry systems. Developing such a system is a task complicated by many factors (social, institutional, biophysical, environmental, and economic). It involves many steps, which are carried out according to need and standard procedure. The goal of the agroforestry system (e.g., fodder production) is very important, as it defines the scope and direction of the activities throughout the whole duration of the system. Once the goal has been established, the appropriate method of assessment must be determined. Torres (1983) identified the major role of the system as a productive or a service role. It is important to recognize these roles in planning the development of an agroforestry system for fodder production.

To develop an effective and efficient agroforestry system, certain criteria must be met. These criteria have been emphasized by Raintree (1984) in the "diagnostic and design methodology" of agroforestry for rural development.

Productivity

Fodder production should be in line with anticipated output. Because land is a fixed input, to increase its productivity, other productive agents (e.g., labour, technology, fertilizer, species) must be considered. Choosing fertile land is a major advantage. Therefore, land can be used to bring the land into the "highest and best use" (Barlowe 1986).

Productivity is essential at all levels of operation and is influenced considerably by the quality of the land. This is particularly important when the agroforestry system is implemented on marginal land, where other inputs are required in considerable amounts to improve the system's productivity.

Sustainability

Sustainability is essential. However, it must not be ensured at the risk of decreasing yield, increasing soil erosion, and increasing nutrient loss. Factors that must be considered to maintain the land for continuous production are species, slope, scale of operation, management practice, and timing of operations. When developing a new system, the system should produce maximum output in an optimum time period.

Another important aspect that requires attention is the carrying capacity in a grazing area. Grazing pressure should be introduced in an agroforestry system by limiting the number of units in a particular unit of land. In the long run, this practice will greatly improve the overall production system.

If sustainability has to be pursued, carrying capacity and the previously mentioned factors should be combined. Many alternatives can be evaluated and attained through increased knowledge on cropping pattern, yield, growth, rotation, and cost.

Adoptability

Fodder production is normally associated with people involved in agroforestry management. The agroforestry system must be perceived as desirable by a majority of people. It should have a value that can be perceived objectively by the community. The choice of species, management practices, and tree–crop interface must be fully integrated with the sociocultural practices of a particular land-use system. It is also important that the ultimate assessment be made by the beneficiaries. The system should be periodically evaluated to provide current quantitative information on its use.

Farmers are usually surprised and suspicious when informed that *Gliricidia* spp. is a valuable fodder for ruminants in India (Atta-Krah and Sumberg 1987). This is because gliricidia has been perceived by farmers as a tree of poor fodder value. It is necessary to make local farmers aware of the potential uses and roles of certain species.

Marketability

In some cases, a prime objective might be to increase the level of income of the rural people through fodder production. The system should be able to support an excess of marketable goods. An effective and efficient marketing distribution, either at the farm, community, or national level, should be established. Hegde (1987) pointed out that an ideal marketing network should

- ensure minimum support price to the producers,
- ensure best selling price,
- create additional demand,

- reduce marketing costs, and
- generate additional employment.

Tree species for fodder production

Trees have been a source of feed since ancient times, and continue to be an important feed source in many areas of the world. Species used for fodder production in agroforestry should have the following characteristics (FAO 1987):

- ability to fix nitrogen,
- suitable fodder,
- ability to withstand lopping, pruning, and coppice management,
- fast growth, especially in early stages,
- easy adaptability to planting site and local environment,
- ability to withstand shading intensity,
- resistance to pests and diseases, and
- multiplicity of function (e.g., wood production, erosion control).

The relative importance of each factor varies from one ecological zone to another, depending on needs and priorities.

Tree fodders are useful as protein supplements in a mixed diet of grasses or pasture legumes (Singh and Osman 1987). However, the feeding pattern of the particular animal must first be understood. A scientific understanding of the relationship between weight gain and diet is necessary. In some cases, trees are toxic when used alone; *Leucaena leucocephala* is a good example.

Brewbaker (1987) and FAO (1987) list species that are significant in terms of ecological and economic value for fodder production; the most popular among these are *Acacia aneura*, *Acacia nilotica*, *Cajanus cajan*, *Desmanthus virgatus*, *Gliricidia sepium*, *Leucaena leucocephala*, *Prosopis* spp., *Pterocarpus erinaceus*, *Pterocarpus marsupium*, and *Sesbania grandiflora* (FAO 1987). Of these species, the most promising are *G. sepium* and *L. leucocephala*. Extensive research on various aspects of these two species has been conducted, with the aim of increasing their potential as fodder trees (Pound and Cairo 1983; Wiersum and Dirdjosoemarto 1987). The suitability of *G. sepium* and *L. leucocephala* as fodder trees is because of their following prominent characteristics: fast growth, nitrogen fixation, nitrogen-rich leaves, tolerance to pruning, ability to coppice vigorously, good fodder value, high foliage productivity, vigorous tap-root development, dry-season leaf retention, and high digestibility.

It is important to note that some trees have advantages over others in particular agroforestry systems. Pound and Cairo (1983) noted that *L. leucocephala* was not as effective as *G. sepium* and *Erythrina poeppigiana* when used in a living-fence system. Leucaena does not strike from stem cuttings and normally has to be raised from seedlings.

Some agroforestry systems for fodder production

Many agroforestry systems have been identified and many could be excellent land-use alternatives for fodder production (see Torres 1983). However, research on the role of trees in fodder production is still limited. Most research has concentrated on *L. leucocephala* and *G. sepium*. These species are widely used as components in browsing systems, alley cropping, and living fences. The practice and management of these systems may differ from place to place depending on socioeconomic, environmental, biophysical, and institutional conditions. However, the main concern is that the system must be able to play a role in fodder production and help meet the growing demand for food.

Browsing system

The browsing system is suitable for arid and semi-arid regions. In this system, woody components provide fodder, mainly as a protein-rich supplement during the dry season, and animals often browse a wide range of trees. Individual trees with palatable foliage are often grazed by animals that are not tied or fenced. In this situation, animals can seriously damage the trees.

There are normally two applications of the browsing system (Nair and Fernandes 1985):

- *Planting multipurpose trees in grazing areas*: trees are planted in the grazing area, mainly for fodder, other commercial produce (timber, fruit trees, firewood), and as shelter for the animals.
- *Cut-and-carry forage production*: trees are usually cultivated as a monocrop in a zonal form of agroforestry and cut either by hand or mechanically and fed fresh to animals, either chopped or unchopped, as a component of the diet.

Alley cropping

Alley cropping was originally developed to maintain soil fertility for food crop production. The system began to be used for fodder production after introducing nitrogen-fixation trees as a component. The additional amount of nitrogen added to the system helps improve the fertility of agriculture lands.

Alley cropping offers many advantages to the farmers. Besides maintaining soil fertility and fodder supply, it also prevents shading and provides green manure or mulch to the arable crop (Nair 1984).

Arable crops are normally planted in the interspace (or alleys) between rows (usually 4 m apart) of planted trees or woody shrubs, which are pruned periodically during the cropping season. The planted trees or woody shrubs are mainly for fodder production. The popular species used as fodder trees include *L. leucocephala*, *C. cajan*, and *G. sepium* (Fig. 1). These species are well-known for their high protein content and suitability as animal feed. An animal component (small ruminants) could also be introduced into the alley-cropping system.

Trees are pruned at the end of 1st year and subsequently managed through

Fig. 1. Alley cropping of *Leucaena leucocephala* and maize in Malaysia.

periodic prunings of the regrowth. This is to ensure that food crops are not shaded (Atta-Krah and Sumberg 1987).

Living fences

The living-fence system of fodder production is common in tropical America (Budowski 1987). The trees in this system are used not only for fodder but also for fuelwood and food. The use depends on the priority and need of the particular area. Trees also act as windbreaks and protection for wildlife.

According to Budowski (1987), living fences refer only to those areas established by planting large cuttings that easily produce roots and on which several strings of barbed wire are attached to keep livestock in or out. In this case, a single row of trees are planted.

Using living trees as fences reduces input costs. New branches will also contribute to filling up an "old" fence.

Species choice is very important. The tree must be a fodder tree, easily propagated, able to grow quickly at initial stage, and able to withstand frequent lopping and strong wind. Common species used in living fences include *L. leucocephala*, *G. sepium*, *E. poeppigiana*.

Home gardens

Home gardens are a common feature in the tropical world. It is one of the most stable agroforestry systems. A home garden consists of a mixture of perennials and annuals of different heights, forming a multistoried structure approximating the forest structure. In many countries, multipurpose trees are used. They provide shade to lower plants, wood for fuel, and foliage for fodder. *Leucaena* *leucocephala* is again the most commonly used species in home gardens, especially in the Philippines and Thailand.

Fodder production in this system is limited. However, the prospect of using home gardens to raise small ruminants is quite promising.

Merits of agroforestry

The agroforestry systems that have been developed and identified have their own qualitative and quantitative merits. These merits can be both tangible and intangible (Table 1).

Agroforestry is an alternative land-use system that can increase food production by combining livestock and trees in a unit of land. As such, land is used at its optimum level of production thus increasing its capacity to benefit the rural population. This is important where the income level of the rural population is low, soil fertility needs to be maintained, and long-run food production needs to be increased. The system is even more promising where land is the limiting factor in livestock grazing.

As the system becomes acceptable to smallholder farmers, the cost of inputs decreases. This is a definite advantage in developing countries because small-scale farmers lack cash and cash flow. In living fences, for example, planting with *G. sepium* will reduce the requirement for wire mesh, thereby saving the farmer a considerable amount of money.

Trees are fully used in agroforestry. Leaves, pods, and bark are used as fodder. Stems and branches are often used as firewood, helping to overcome energy-supply problems.

Table 1. Facilitating factors in the implementation of agroforestry systems for fodder production.

Factor	Components
Ecological	• Efficient use of natural resources • Decrease the hazards of environmental degradation
Economic	• Increase production per unit land • Various components might be used as inputs for production of others, thus decreased commercial inputs • Increase tree production and reduced cost of tree management
Socioeconomic	• Provide employment opportunities and regular income • Tree products can be obtained in off season • Require low management skills • Low risk in tree and livestock management • Production can be directed toward self-sufficiency or marketing
Psychological	• More easily acceptable to the local population
Political	• A tool for settlement of shifting cultivators

Source: Wiersum (1981).

Scientific land-use management could be applied to agroforestry. Therefore, research in this area is becoming more important for the optimum use of land resources.

Intensive development of agroforestry systems can promote and accelerate rural development by creating employment opportunities, improving infrastructure facilities, and generating linkages among all sectors in the economy. As such, participation in agroforestry projects should be encouraged to further improve the standard of living of the rural poor.

Weaknesses of the system

Agroforestry systems are not without problems. Many are associated with socioeconomic, sociocultural, biophysical, institutional, and technological aspects of the system (Table 2).

The rapid development of a system relies heavily on the socioeconomic situation of the rural people, particularly the farmer who is involved in tree fodder production. Lack of educational facilities, low income level, lack of farmer participation, lack of entrepreneurship, and lack of working capital are some problems that may deter system development.

Another weakness in agroforestry is the lack of research and development. Scientific research is urgently required on the use of tree fodders for certain animals, feeding habits and patterns, management practices, arrangement of the system, and matters related to participation.

It is often difficult to introduce tree management for fodder production into a new area. It is easier to introduce new and better species if trees are already part of the traditional land-use system. The long production period of a certain species may be unattractive to local farmers. The risk of introducing such a system is high because of the limited financial resources the farmers have on hand.

Method of evaluation

Over the past few years, the planning and development of agricultural research at international and national research institutions has been passing through a revolutionary stage. Many new research methods have been developed as a result of the development of farming system research (FSR). Research priorities are derived from diagnostic problems and potentials in existing farming systems as well as by the use of on-farm research methods to assist in the development of appropriate technologies in agroforestry systems.

The lessons learned from past experiences in FSR have contributed to the development of a standard methodology in planning and developing agroforestry systems in various ecological and sociological zones throughout the world. Potential trees for fodder production and their characteristics, management practices, potential areas, and other environmental and technological requirements will be fully explored and identified.

As a predominant land-use system, every facet of agroforestry must be studied

Table 2. Constraining factors in the implementation of agroforestry systems for fodder production.

Factor	Components and degree[a]
Socioeconomic	• Low productivity (m)
	• Lack of educational facilities (h)
	• Low level of education (h)
	• Little participation from farmers (m)
	• Lack of entrepreneurship (m)
	• Lack of working capital (h)
	• Lack of incentives provided to farmers (h)
	• Disciplinary problems (l)
	• Motivating factors are not present (h)
Sociocultural	• Customs and traditions (h)
	• Lack of awareness of the system (h)
	• Negative image of the system (h)
	• No leadership at community level (h)
	• Local politics involved in making decision (m)
	• Women have no role in the system (l)
	• Territorial jealousy (m)
	• Tenure problems (h)
Biophysical	• Problems of species suitability (h)
	• Problems of land-use pattern (m)
	• Uncontrolled grazing land and protection (h)
	• Scarcity of arable land for fodder production (h)
Institutional	• Shortage of trained, experienced staff (h)
	• Lack of research and development (h)
	• Budget constraints (h)
	• Narrow framework and coverage of the official program (m)
	• Time and scheduling of the programs are not well coordinated (m)
	• Minimal extension effort (h)
	• Lack of training and management techniques (h)
	• Unequal distribution of benefits (h)
	• Small market outlet (h)
	• Lack of coordination between implementing agencies (m)
	• Weak organization at community level (m)
	• Local markets cannot absorb large supply (h)
	• Problems of property rights (m)
Technological	• Complicated fodder production system (h)
	• Lack of appropriate technology (h)

[a] The degree shows the relative importance of each factor influencing the effective implementation of fodder production in a particular area: h, high; m, medium; l, low. The way it affects either enhances or impedes a particular system in which the factor exists.

and better understood. Only then, can a rational and sound approach be suggested as to how, why, and in what manner such a system should be developed and implemented.

The need to evaluate tree fodder production arises because of the

- variety and complexity of agroforestry systems for fodder production,

- heterogeneity in management practices with respect to ecological, geographical, and social conditions,
- greater weight given to conservation in most countries practicing the system for fodder production, and
- different levels of operation that may exist as a result of constraining factors in tree fodder production.

The International Council for Research in Agroforestry (ICRAF) developed an evaluation method called diagnostic and design (D & D). The main purpose of the D & D methodology is to identify priorities for research, to develop and test sound agroforestry technologies, and, subsequently, to disseminate these technologies around the world. The practical objective of ICRAF's D & D methodology is to assist agroforestry workers to formulate and develop a good agroforestry system that can be implemented and studied. The approach is problem oriented in nature and is appropriate for evaluating agroforestry systems for fodder production.

Basically, the D & D methodology involves several stages (ICRAF 1983; Raintree 1984, 1987):

- *Prediagnostic stage*: environmental description of the study area, identification of distinctive land-use system, and preliminary description of the selected land-use system(s).
- *Diagnostic stage*: information gathering on land-use problems and potentials, diagnosis of major land-use problems and potentials, and design specifications for problem solving and potential alternative technologies.
- *Technology-design stage*: appraisal of alternative technologies for further consideration, design of selected technologies (general and specific), and ex ante evaluation of the proposed design technology.
- *Follow-up planning stage*: identification of research needed to develop and test the components suggested in the proposed technology, identification of further topics for further survey or redesign of a similar technology, and guidelines for implementation of follow-up project activities.

The D & D methodology can identify and formulate an appropriate technology that can be implemented in a particular area. Further evaluation of the system should also be done through intensive on-farm or on-station research.

Strategies for effective implementation

To ensure effective implementation, the following policies and strategies are recommended. The degree and manner in which the proposed strategies should be followed may differ from one area to another based on socioeconomic, biophysical, institutional, and technological improvements and advancements.

- Optimize integrated land-use capacity in both private and public land for fodder production.
- Strengthen land tenure and other legal aspects in relation to property rights and the right to use the land and other land resources.

- Inculcate an awareness and positive attitude into rural farmers with regards to fodder production as a means of improving socioeconomic conditions.
- Identify market demands and outlets for outputs.
- Encourage product diversification in a unit of land to increase land capacity and bring the land to its full potential.
- Promote participation in tree fodder production through social forestry programs or other rural development projects.
- Strengthen research and development in areas where further improvement on existing systems is required (also, prioritize research areas, level of research, and scope).
- Enhance extension services to provide and expose rural farmers to available technologies in fodder production.
- Increase institutional support for the desired objective, which is in line with government policy to increase food supply and eradicate poverty in rural areas.

Conclusion

In view of its potential in helping to meet the increasing demand for food, energy, and environmental conservation, agroforestry is an important form of land use. However, it is not the only solution to land-use problems. Even though agroforestry offers great possibilities in fodder production, its development must be properly planned and evaluated. Success will be achieved if a more holistic approach is adopted and the research support is provided to put new technologies into practice.

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Economic aspects of using shrubs and tree fodders to feed farm animals

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Abstract — *Shrubs and trees can play an important role in increasing feed supplies on small farms and among landless livestock owners. These feed sources are especially important during critical periods of feed shortage, such as during the dry season. Increasing shrubs and trees may reduce the pressure on farmers to unwillingly sell livestock because of feed shortages and, thus, receive a lower price. A framework to conduct simple economic analysis is outlined and researchers are urged to directly participate in on-farm testing of new shrub and tree interventions. Researcher participation at the farm level to describe, diagnose, design, test, and evaluate the potential of trees and shrubs as an alternate feed source can also rapidly transfer appropriate technology to small farmers. Because trees and shrubs provide low-cost feed to a majority of small producers, it is important that policies be adopted to encourage agroforestry opportunities that increase their availability.*

Résumé — *Les arbustes et les arbres peuvent contribue substantiellement à accroître les fourrages dont disposent les petits exploitants agricoles et les propriétaires de bétail sans terre. Ces sources de fourrage sont particulièrement importantes lors de pénuries de fourrage durant la saison sèche. L'accroissement des arbustes et des arbres pourrait réduire la nécessité devant laquelle se trouvent les paysans de vendre leur bétail faute de fourrage et d'en tirer alors un prix inférieur. L'auteur donne les grandes lignes d'un cadre pour effectuer une analyse économique simple et exhorte les chercheurs à participer directement aux essais en ferme de nouvelles interventions ayant trait aux arbustes et arbres. La présence des chercheurs à la ferme pour décrire, diagnostiquer, tester et évaluer le potentiel des arbres et des arbustes comme autre source de fourrage peut aider à rapidement transférer la technologie appropriée aux petits paysans. Parce que les arbres et les arbustes offrent un fourrage peu coûteux à un grand nombre de petits producteurs, il est important que des politiques soient adoptées pour favoriser les possibilités agroforestières qui en accroîtront le nombre.*

Resumen — *Los arbustos y árboles pueden desempeñar un papel de importancia para incrementar las provisiones forrajeras a granjas pequeñas y a ganaderos que no poseen tierras. Estas fuentes alimenticias son especialmente importantes durante los períodos de escasez forrajera, tal como la estación de sequía. El aumento de arbustos y árboles puede evitar que los granjeros deban optar por vender el ganado como consecuencia de la escasez de forraje y recibir, por consiguiente, un precio inferior. Se bosqueja un sistema para llevar a cabo un análisis económico simple, y se insta a los investigadores a participar directamente de la verificación práctica, en la granja, de esta nueva inclusión de árboles y arbustos. La participación de los investigadores a nivel de granja, para describir, diagnosticar, proyectar, verificar y evaluar el* *potencial de árboles y arbustos como fuente alimenticia alternativa puede también ayudar a la rápida transferencia de tecnología apropiada a los pequeños agricultores. Es importante adoptar políticas en pro de una agroforestación que incremente la disponibilidad de árboles y arbustos, ya que éstos proporcionan alimento de bajo costo a la mayoría de los pequeños productores.*

Introduction

The significance of shrubs and tree fodders in ruminant feeding is secondary to other sources like grasses. However, because feed is the single most important item in the cost of ruminant production, the potential value of low-cost sources like trees and shrubs should be fully explored. This paper attempts to lay out a simple economic analysis of using shrubs and trees, with special reference to small scale farmers and landless and noncommercial producers. These groups especially depend on multiple feed sources; shrubs and trees are, therefore, of much significance. A framework is outlined to evaluate the appropriate methods, data needs, and approaches to on-farm testing and analysis of shrubs and trees in ruminant production.

Together with the limited documentation on shrubs and tree fodders, and their use as a feed source, there is very little economic analysis. Therefore, much of this paper revolves around the author's experience with on-farm animal research and its economic analysis. Because this workshop provides a forum to discuss the potential of shrubs and tree fodders as animal feed, it is reasonable to expect some follow-up action to test and evaluate potential species at the farm level. Many recent workshops have called attention to such widespread effort (Amir et al. 1985; Nordblom et al. 1985; Devendra 1988). Close contact with the farmer is essential for the information generated from this workshop to be used at the farm level.

Contribution of shrubs and trees

In arid to semi-arid areas, trees and shrubs contribute a major portion of animals' daily diet, particularly in systems where animals are grazed. In hot zones, trees and shrubs are a source of shade and animals eat fallen leaves while resting. However, because animals are grazed, the land is often not put to any other use. These ranges often have common property rights and are, thus, poorly maintained. Conversely, in more intensive systems where trees and shrubs play a secondary role, there are more opportunities to develop shrubs and tree fodders. This paper is restricted to the discussion of more intensive smallholder systems.

Ranjhan (1985) reviewed feed sources in Indonesia and the Philippines and pointed out that shrubs and tree fodders provided between 14 and 17% of feed (Table 1). There is a significant relationship between lowland and upland feed availability. Soedomo et al. (1985) reported that *Sesbania* spp. and banana leaves are used in much higher proportion in the uplands compared with the lowlands in Indonesia (Table 2). This has important economic implications, as there may be a comparative advantage in developing shrubs and trees in the uplands. Upland landholdings are usually small and farmers rarely allocate land for forage production. However, on field bunds and along roads, trees and shrubs can easily be grown to increase the overall feed availability. Even though the expected

Table 1. Supply of feed ingredients for cattle and buffaloes (%).

	Dry season				Wet season			
	Grazing	Straw	Trees and shrubs	Other components	Grazing	Straw	Trees and shrubs	Other components
Indonesia[a]	31	50	14	5	79	2	14	5
Philippines[b]	35	45	17	3	85	10	4	1

[a] Source: Nitis (1980).

[b] Source: Moog (1980).

Table 2. Percentage of farmers feeding various forages to small ruminants in West Java.

Forage	Lowland	Upland
Native grass	86	100
Corn tops	2	70
Legume straw	1	32
Rice straw	0	13
Sesbania spp.	20	0
Artocarpus spp.	0	10
Banana leaves	0	72
Cassava leaves	3	22

Source: Djajanegara et al. (1982).

payoffs from this type of research are high, there is a need to improve upland production systems to use more efficiently the increased fodder.

Klusmann (1988) looked at the broader potential of trees and shrubs in tropical and sub-tropical production systems. Devendra (1986, 1987) has stressed the significance of tree leaves for goats in several countries in the Association of South East Asian Nations (ASEAN) region. An important conclusion from his reviews is that browsing (shrubs and tree fodders) alone does not promote high performance, especially in semi-arid conditions. Weight gain under controlled experiments was the lowest when animals were left to browse alone in India (Parthasarathy et al. 1983). However, by combining browse with forage, average daily weight gain was twice as high; when browse was combined with some concentrate supplementation, daily weight gain increased fivefold. Therefore, in making recommendations it is important to emphasize a complete feeding strategy as opposed to one that would rely only on trees and shrubs.

Perhaps one of the most well-researched and promoted species is leucaena (*Leucaena leucocephala*) (Pound and Cairo 1983). Leucaena is being widely tested and used in several countries in Asia and Latin America. In India, it is reported to provide a hedge against the failure of dryland sorghum fodder (Walker 1988) and reduce the risk from inadequate feed. Given its hardy nature, leucaena can withstand high environmental stress.

Potential economics of trees and shrubs

It may be difficult to justify tree planting for the sole purpose of fodder production, as most trees have multiple uses on small farms (e.g., fuelwood, fruits, shade, mulch, windbreak) (Beer et al. 1985). Trees also have a time dimension and,

Table 3. A hypothetical illustration of benefit–cost analysis applied to tree fodder production.

Technical assumptions

Fodder production (kg) from five trees on a small farm planted on barren land and along bunds:
Year 1 = 0
Year 2 = 500
Year 3 = 750
Year 4 = 450
Year 5 = Farmer cuts and sells tree

Economic data

Planting cost = 3 500 IDR[a]
Annual maintenance and security cost = 2 000 IDR
Opportunity cost of land for 5 years = 50 000 IDR
Shadow price of 1 kg leaves = 45 IDR
Interest rate = 10%/year
Minor economic benefits from shade for animals and fuelwood from leftover twigs are added to yearly benefit stream.
Sale of five adult trees at end of 5 years = 150 000 IDR

Year	Cost	Benefit	Discount factor	Discounted cost	Discounted benefit	Discounted net
1	5 500	0	0.909	4 545	0	4 545
2	12 000	25 000	0.826	9 912	20 650	10 738
3	12 000	37 500	0.751	9 012	28 162	19 150
4	12 000	22 500	0.683	8 196	15 367	7 171
5	30 000	150 000	0.621	18 630	93 150	74 520
Total				50 295	157 329	107 034

Benefit–cost ratio = 157 329/50 295 = 3.12

[a] In July 1989, 1 740 Indonesian rupiah [IDR] = 1 United States dollar [USD].

thereby, an opportunity cost, because they compete for scarce farm land. Because benefits from trees are derived over a lifetime, it is appropriate to consider the economic contribution in terms of discounted net benefits and costs over the life of the tree. Hence, both financial and economic analyses are recommended. The relevant parameters that are generated from this type of analysis include annual values for discounted benefits (*B*) and costs (*C*), *B*/*C* ratios, and internal rate of return. Shrubs have a shorter life span and simpler tools like partial budgeting are more appropriate.

An illustration for the economic analysis of fodder producing trees is provided in Table 3. Further details on procedures, with examples for on-farm economic analysis of animal trials including feed experiments, can be found in Amir and Knipscheer (1989). The information needed for such an analysis includes

- life cycle of the tree,

- amount of fodder produced per tree or for a number of trees in a given area; and time of year and frequency when fodder is available,
- maintenance costs (labour, pruning, fertilization),
- value of fodder produced, and
- salvage value at completion of life cycle (including expected income from the wood minus cost).

From this data, the *B/C* ratio can be derived. As long as benefits exceed costs, fodder produced from trees and shrubs is economical. In practice, however, a farmer's decisions are often influenced by land availability and his or her knowledge about the short- and long-term expected benefits from the tree.

To determine immediate fodder benefit from trees or shrubs, the contributed value to daily, weekly, or monthly feeds should be estimated on the basis of costs of alternative feeds (i.e., shrubs and forage). For simplicity, first estimate the value of labour and time that would be involved if the farmer had to collect a similar amount of another feed (e.g., grass) to meet daily requirements. Caution should be taken to value similar types of feeds. For instance, if shrubs and tree fodders are used to supplement or substitute grass grown on the farm, the value of the shrub and tree fodders would be equivalent to the market price of the fodder. Because many types of fodders are not valued in the open market, shadow prices can be derived by comparing the labour requirements and cost of production for close alternatives. Special attention should be given to assigning feed values during critical feed-shortage periods, like the dry season, when shrubs or tree fodders may be the only available source. A premium should be placed on shrubs and tree fodders when they allow farmers to withstand forced selling at a lower price because of a lack of feed. This is especially true in environments where farmers reduce stock because they cannot find feed (Nygaard and Amir 1988).

Degree of acceptability and economic evaluation

An important economic technique to derive perceived benefits from trees and shrubs is to question farmers about their willingness to pay for a shrub or tree fodder bundle or to lease shrubs or trees for fodder production over a fixed period. This information should be supplemented with some index that shows animal preference for different shrubs and tree fodder species. A qualitative measure of acceptability of trees and shrubs by livestock can be developed. Lusigi (1984) reports such an index of acceptability for different plants, including trees and shrubs by animal species (Table 4). Such preference indices need to be developed for different breeds of animals for a diverse range of agroecological conditions. This data will provide a useful check on overvaluing the contribution of any shrub or tree.

The same is true for the interaction between shrubs and trees in relation to the animal component of the farm system. There is widespread descriptive research in this area with little attention to quantification. Particular attention has been given by ecologists who look at the broader contribution of agroforestry on small farms (Altieri and Farrel 1984; Balasubramanian and Egli 1986; Nair and Sreedharan 1987). Unless this information is applied to solve actual farm problems, it is unlikely to prove useful to animal scientists.

Table 4. Degree of acceptability (%) of different fodder by various animals.

	Rainy season				Dry season			
	ML	D	A	NL	ML	D	A	NL
Camels								
Trees and large bushes	2	26	29	43	2	24	14	60
Bushes	6	33	17	44	—	17	22	61
Dwarf bushes	—	41	15	38	3	41	29	27
Resistant grasses	—	—	14	86	—	—	18	82
Herbs	3	16	10	71	2	4	9	85
Annual grasses	—	—	5	95	5	—	24	71
Others	7	43	29	21	14	—	—	86
Sheep								
Trees and large bushes	—	—	—	100	—	5	11	84
Bushes	—	5	17	78	—	—	11	89
Dwarf bushes	—	23	15	62	—	12	35	53
Resistant grasses	5	86	5	4	82	9	9	—
Herbs	3	12	20	63	3	2	10	85
Annual grasses	10	74	16	—	8	74	13	5
Others	21	29	14	36	—	14	—	86
Goats								
Trees and large bushes	5	34	13	48	2	21	27	50
Bushes	6	22	33	39	—	11	33	56
Dwarf bushes	7	33	18	42	1	28	42	29
Resistant grasses	—	36	23	41	—	23	36	41
Herbs	4	24	32	40	—	4	16	78
Annual grasses	—	11	42	47	15	21	32	47
Others	14	50	14	22	15	22	—	63
Cattle								
Trees and large bushes	—	—	—	100	—	—	3	97
Bushes	—	—	6	94	—	5	12	83
Dwarf bushes	—	3	9	75	—	12	29	59
Resistant grasses	4	86	5	5	—	86	5	9
Herbs	3	5	13	79	3	2	10	85
Annual grasses	10	75	13	2	9	61	24	6
Others	—	36	—	64	—	7	14	79

Note: ML, much liked; D, desired; A, average; NL, not liked.
Source: Lusigi (1984).

Data needs

Most of the data on the contribution of shrubs and tree fodders to animal feeds is too experimental, making it difficult to draw reliable conclusions for application under farm conditions. Also, and often, results are based on too few observations with little attention to quantification. Obviously, there is tremendous scope for improvement in the type and extent of data collection, and animal scientists can team up with agroforesters and social scientists to jointly eliminate this need. Much of the information gathered will have to focus on socioeconomic variables such as labour, access to roads, fodder prices, and peak fodder demand periods.

Besides the data requirements for economic analysis, a minimum data set at the village and farm level should include information on the following:

- *Land and forest regulations*: usage (is private access allowed, uses of specific shrubs and trees); availability of support for village-level participation to develop shrubs and trees; and government regulations and policy objectives.

- *Property rights and common practice*: patterns of ownership and tenure; free use and sharing arrangements of trees; responsibility for maintaining shrubs and trees; controlled versus uncontrolled usage; and home gardens and farms where trees are planted, their ownership, and underlying objectives.
- *Uses and excess of shrubs and trees*: characteristics of preferred species; restrictions on use (cultural and religious); shrub and tree management systems; agroforestry development efforts; methods of supplementation and feeding (i.e., chopped, mixed, and chemical treatments); and differences in shrubs and tree fodder usage by animal species.

This list is in no way complete and many other dimensions can be added. Some of the information can be obtained from secondary sources (national, provincial, or village-level statistical books). Others will require direct farmer contact with formal or informal survey instruments.

To realistically evaluate the farm-level feed potential of shrubs and tree fodders, data must be recorded on a regular basis. This will enable research results to be evaluated and extrapolated to wider recommendation domains. A few case studies across dominant agroecological regions can also provide useful information on how trees and shrubs contribute to the feed resource base.

On-farm testing

On-farm animal research aims to test selected technical interventions at the farm level. To generate such information, it is important that the researcher develop a research agenda that directly allows for farmer participation. The benefits of this type of research are significant in terms of understanding the farmer problem and testing of potential interventions under farm conditions. Unless attention is given to this type of on-farm research, it is doubtful that the existing knowledge can solve prevailing livestock-production problems.

Shrubs and tree fodders should be viewed as new technologies that can increase livestock productivity. Because farmers are already aware of many shrub and tree species, a preliminary inventory of local species should be the first step in designing an on-farm testing program. The farmer's knowledge about these species, although indigenous, is based on long experience and should be shared with the researcher. After a careful description and diagnosis of the feed problem (including critical feed-shortage periods, rainfall, agroecological suitability of trees, social customs and tree tenure), potential interventions, such as when to cut the forage, introduction of new species most suited for animal feed, and strategies for feeding, should be explored. Once the purpose of such introductions is understood, the farmer should be encouraged to plant these shrubs and trees. However, existing species in the area should not be ignored; their significance should be highlighted. Where the introduction of trees has multiple objectives (fodder, fuel, shade, fruit, wood, and compost), farmers should be educated on the timing of the benefits, with special reference to fodder.

Some researchers may be reluctant to get involved in testing new shrub and tree species because of their long life cycle. This need not be the case, provided testing is done with a clear objective to assist the farmers. Perhaps this type of research should be coordinated through universities and government departments. Short projects are not suitable for generating this type of information.

Conclusions

Future efforts to experiment with trees and shrubs at the farm and village level should proceed in a systematic manner. Attention should be given to document the existing species, their nutritional content, and significance as animal feeds. The results of economic analysis under various sensitivity assumptions to develop strategies of economic advantage and sociological impact, to existing farming systems will need special attention. Although there may be a tendency for animal scientists to view shrubs and trees only from the viewpoint of fodder production, it is concurrently important to take a much broader view of the benefits and costs to farmers in methods of extension.

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Discussion

The fifth and final session of presentations featured the processing, methodology, and economics of shrubs and tree fodders. Three papers were presented.

The first paper, presented by Dr Reddy, described opportunities for processing. In India, fallen tree leaves along with leaves lost as a result of lopping amount to 43×10^6 t/year. Several experiments have demonstrated that grinding leaves improves animal performance. Processing has also enabled the formulation of complete, pelleted diets, which aid in making animal production more economically sound.

Simple machines will perform chaffing, grinding, briquetting and, waffering. In addition, practical, low-cost grinders, conveyers, pelletizers, extrusion cookers, and driers are necessary to extend the value of complete diets and ensure quality control.

The second paper, presented by Mr Awang Noor, described the development and evaluation of agroforestry systems for fodder production. The criteria to be used in establishing fodder production in an agroforestry system were outlined, together with procedures for development. Discussion centered on methods of evaluation, multidisciplinary team efforts, and social forestry.

The final paper in this session, presented by Dr Amir, dealt with the economic aspects of using shrubs and tree fodders as animal feed. Dr Amir outlined a simple economic analysis for researchers and emphasized direct participation in on-farm testing of new shrub and tree interventions. Other issues that were emphasized included the need to analyze fully the resources available, cost–benefit analysis, knowledge of land and forest regulations, property rights, and the need for effective communication.

Conclusions and Recommendations

There are two main features of this international workshop that are worthy of mention. First, this meeting represents the first attempt at examining and discussing in detail the available knowledge on shrubs and tree fodders. In turn, this gave an excellent indication of the extent of research and development within national programs in individual countries. Second, participation in this meeting was distinctly multidisciplinary, with a rare mix of agronomists, animal nutritionists, veterinarians, biochemists, feed technologists, agroforesters, economists, and extensionists, whose collective presence generated different points of view and very useful discussions. The major observations that emerged from this interaction were that the knowledge base was generally very sparse, procedures and approaches to intensify wider use of these feeds need clearer definition, and a great variation exists between national programs on research on shrubs and tree fodders.

The conclusions and recommendations of the workshop were the results of three working groups. The participants were grouped according to discipline and specialization, and the recommendations have been categorized into four sections: shrub and tree fodder resources, use by farm animals, the three-strata forage system, and methodology, economics, and information exchange.

The conclusions and recommendations recognize the different agroecological zones in the developing world (semi-arid, arid, humid, and high-altitude, tropical) as well as the many different production systems. More particularly, these recommendations have been made in the context of need for a multidisciplinary team effort on various aspects of fodder research and development, including participation of farmers in whole-farm systems. Central to this approach is the task of increasing the use of feed materials appropriate to individual agroecological zones and of potential value to farmers.

Shrub and tree fodder resources

Germ plasm diversity and availability

Most research and development on tree fodders has been confined to a few genera. The danger of depending on a narrow genetic base has been highlighted by the severe insect damage to *Leucaena* by psyllid.

Country papers have indicated a wide range of shrub and tree species that are fed to farm animals. In most instances, however, there is little knowledge about their agronomic potential and specific use for animal feeding. Other lists of shrub and tree species for animal feeding have also been identified. Therefore, the problem is not a lack of potential species, but rather the need to rationalize these lists and focus on research and development with a small group of promising species.

It is strongly recommended, therefore, that promising tree and legume species be ranked in relation to their potential as animal feeds within agroclimatic zones. This should be based on a standard agroclimatic zonation across countries, where each country can provide a list of the potential species and their uses for prevailing agroclimatic zones.

This information could be consolidated into a comprehensive document listing promising species and their potential uses for each agroclimatic zone. Secondary information could also be included on edaphic adaptation and the availability of seeds for further evaluation. It is suggested that this activity be part of an existing information network. It is also recommended that germ plasm collections of shrubs and trees, ecotypes or species, should not be initiated until established potential uses have been identified for particular genera or species.

Germ plasm evaluation

Genetic evaluation of species or genera should only proceed after their potential has been determined. As much genetic diversity as possible should be included among the species being evaluated.

It is recommended that a standard design be used for all germ plasm evaluations. Also, a standard tree species should be included in the design (e.g., *Gliricidia*) so that the results can be compared across sites and regions. It is suggested that the standard design used in the Forestry, Fuelwood, Research and Development (FFRED) network could provide a basis for uniformity of approach and methods of evaluation.

Following the identification of well-adapted, promising species, research will be needed to define optimum management strategies. The goal of this research would be to maximize productivity and sustainability of fodder species in the various animal production systems and agroclimatic zones.

Selection for feed quality

In most situations, shrub and tree species are required as a supplement to low-quality feeds. Emphasis and selection of shrub and tree species should therefore be based on feed quality, including high nitrogen content, digestibility, and low degradability of nitrogen in the rumen. Forage source selection should give priority to leguminous (nitrogen-fixing) shrubs and trees because of the high leaf quality and higher sustainable growth rates compared with nonleguminous species.

Use by farm animals

Much more information and a thorough inventory is required on shrubs and tree fodders. This should involve identifying potentially useful feed sources, rates of productivity, and complete characterization to include types of species, varieties and cultivars, agronomic characteristics, stage of cutting, season of sampling, and whether the leaves or stems were used.

Information on the nutritive value of these feed materials is consistently sparse in most counties in the tropics. Consequently, it is recommended that there be more complete assessments on this aspect to increase the level of information. Assessments should focus on those potentially important feeds for which the current information is inadequate.

There is also an urgent need to document feed compositions and nutritive values specific to shrubs and fodders in each country. The following measurements are recommended for the assessment of feeds:

- Fiber (neutral-detergent fibre, acid-detergent fibre, and lignin),
- Metabolizable energy (ME),
- Minerals (Ca, Mg, P, and Na),
- In vitro dry matter digestibility (DMD),
- In sacco DMD,
- In vivo DMD,
- Nitrogen degradability in the rumen, and
- Total phenols.

The following animal measurements are recommended:

- Acceptability based on voluntary feed intake,
- Palatability,
- Digestibility,
- Period of adaptation to measure the time taken to accept individual feeds,
- Production responses (meat, milk, fibre, draught power, and eggs),
- Feed conversion, and
- Side effects related to deleterious principles.

When assessing tree fodders that are fed as a sole feed, it is important to ensure that the voluntary feed intake is at least 1.6% body weight, ensuring adequate nutrient requirements for maintenance. Because of apparent differences in the period of adaptation to some feeds, observations are concurrently required on the conduct and duration of digestibility trials. Where minimum intake is not feasible, a mixture of feeds must be used and digestibility must be determined by a difference method.

With specific reference to nonruminants, there is a parallel need to define protein quality in terms of amino acids and pigment content, and to measure xanthophyll content. During feeding trials, statistically valid designs should be used to include a clear definition of the methods applied, the parameters to be measured, and the duration of the trials. With specific reference to shrubs and tree fodders, more information is required on the selection of feeds and feeding behaviour.

Apparent problems with acceptability and palatability of tree fodders are only valid if based on long-term feeding trials. In view of the differences in feeding behaviour and responses by animals, specifically to shrubs and tree fodders, more information is required on their use by animals.

The value of shrubs and tree fodders must also be investigated in year-round feeding systems. This could include long-term studies on production responses and reproductive performance.

Strategic supplementation is important in many production systems for ruminants, especially in difficult environments. Because of the potential importance of many of these tree fodders as protein supplements (20% crude protein content), more research and development effort is necessary on feeds, feeding methods used, response in animals, and economic assessment. In this context, the value of leguminous fodders, such as *Acacia* spp., *Leucaena*, *Gliricidia* spp., *Erythrina* spp., and cassava leaves (*Manihot esculenta*), are especially important.

Under more extensive conditions, especially in semi-arid and arid environments, more detailed studies are required on the selection and utilization of browse by individual ruminant species and the performance of animals. Procedures for sampling and mixing feeds, proportions used, and effectiveness of individual feeding systems also need more documentation.

The value and extent of sun drying, conservation, and storage also need more study. Inadequate attention has been given to these aspects, and improved practical methods for small-scale conservation and storage need to be more thoroughly investigated.

There is a wide variety of antinutritional factors, including various toxic compounds. These need to be more completely identified and thoroughly investigated, including their effects on individual animal species. Associated with the use of these feed materials, antinutritional factors, and feeding trials, differences between species on thresholds of tolerance to toxic substances also need to be examined.

Processing

Processing suitable shrubs and tree fodders has shown potential value; however, research and development efforts on processing must be expanded to involve promising feed ingredients. Elements in this type of work include choice of feed, appropriate enrichment, development of complete feeds, commercial testing for economic viability, and quality control.

Type and economical suitability of feed-processing units of different sizes should also be assessed. Machines assessed should include those for chaffing, grinding, briquetting, and waffering, as well as low-cost grinders, conveyors, pelletizers, extrusion cookers, and dryers.

The three-strata forage system

Crops, livestock, and agroforestry are well integrated in the three-strata forage system (TSFS). The system has been thoroughly researched and found to be beneficial to farmers. The nature of the research is necessarily long term, but there is wide appreciation of the progress that has been made, the results generated, the experience gathered, and the benefits to subsistence farmers, and the economy and ecology of Bali.

Many suggestions were made to extend the value of the results:

- Stratification of both TSFS and the traditional system must be considered on the basis of differences in soil type and topography.
- Differences in forage and animal productivity must be related to differences in topography and soil. As a result, in subsequent recommendations to farmers, the choice of areas for forage production can be based on the soil and topographical features of an individual farm.
- Soil scientists should be consulted when measuring changes in organic matter, fertility, soil–water relationships, and erosion levels in TSFS and the traditional system.
- Data generated must be thoroughly analyzed to interpret the value of potential fodder species and how they will react to different locations.
- More economic analysis is required on returns to investment, and all aspects of direct and secondary benefits to farmers need to be assessed.
- Through appropriate communication and extension methods, TSFS should be promoted outside Indonesia.

Methodology, economics, and information exchange

Extending the value of shrubs and trees will depend on the data accumulated from surveys, observation, and monitoring; the choice and use of such feed materials by farmers; and research and development. Farmers' perceptions, constraints at the farm level, and how potentially promising interventions can enhance a prevailing farm situation will also be particularly important. Such approaches are very rare and are worthy of a more concerted effort as part of farming-systems research.

The working group made many recommendations with respect to methodology, economics, and information exchange:

- When evaluating promising fodder trees, the researcher should consider interactions with, and effects on, grass, shrub growth, and crops in the same area, including the effects on the soil and crop yields.
- On-farm animal research is gaining increased attention in national programs; this trend should be encouraged and experiences should be shared.
- Animal scientists should directly participate in the description, diagnosis, design, testing, and evaluation of technology. Where possible, other disciplines should be involved in the planning stages of the experiment.
- Several agencies together can play an important role in initiating on-farm research, notably universities, and research and extension departments. Agribusiness firms that are likely to benefit from the research results should be involved in the planning and execution of the project.

- On-farm research must carry a specific research bias, in which the hypothesis, objectives, and methods used are defined and always kept in view. These elements are essential in participatory research with farmers who are likely to benefit from the joint efforts.
- In some cases, limited subsidization of treatments may be necessary to involve the participation of farmers. However, the resources used for this purpose should be budgeted.
- Researchers should work together with extension workers and not merely be satisfied with generating new knowledge. Inherent weaknesses in the extension system should be recognized with a view to improving them.
- Linkages between government research and other research and development agencies, including nongovernmental organizations, should be encouraged.
- Training in economics is urgently needed for animal scientists involved in on-farm research, project formulation, and research management.
- Economists in research and development activities should be encouraged to interact with animal scientists to specifically meet the requirements of project activities.
- A wider distribution of experiences and recent advances needs to be encouraged in animal research and development oriented to small farmers.
- Regional networks are valuable in encouraging the flow and exchange of information. For this reason, wider use should be made of communication materials and tools, such as audiovisual aids, particularly low-cost tools.

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